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Title-page and Contents of Volume XIV are enclosed

HYDROBIOLOGIA publishes original articles in the field of Hydrobiology, Hydrography and Protistology. It will include investigations in the field of marine and freshwater Zoo- and Phytobiology, embracing also research on the Systematics and Taxonomy of the groups covered. Preliminary notices, polemics, and articles published elsewhere will not be accepted. The journal, however, contains reviews of recent books and papers.

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Bacteriological aspects of pollution in the Jukskei - Crocodile river system in the Transvaal, South Africa

by

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I. INTRODUCTION

The Department of Nature Conservation of the Transvaal Provincial Administration decided in 1955 to establish a Fellowship within the Water Research Division of the S.A. Council for Scientific and Industrial Research, with the purpose to conduct a series of river surveys. Although the original plan envisaged the investigation of a number of river systems which were known to be subject to various forms of organic and inorganic pollution to the detriment of the natural fauna and flora, the project was then limited to a detailed survey of the Jukskei—Crocodile System which drains Greater Johannesburg towards the North, and which receives the effluents from four conventional sewage treatment plants serving Eastern and North Eastern Johannesburg.

The objectives of the survey, as laid down in the First Report to the Steering Committee (1), were:

(i) To determine the present chemical and biological conditions in the streams forming the Jukskei—Crocodile System;
(ii) To determine sources of pollution and their effects on biological conditions in the streams;
(iii) To formulate biological indices for various types of pollution; and
(iv) To investigate possible methods to improve the pollution problem.

The Water Research Division of the S.A. Council for Scientific and

Industrial Research provided algological and bacteriological services to the Provincial Administration, and facilitated the chemical investigations. The results of algological studies have been published (2), the biological and chemical findings are being prepared for publication (3), and the data obtained in a detailed bacteriological study of the Jukskei—Crocodile System are presented and discussed in this paper. These investigations deal practically exclusively with the adventitious bacterial population of the streams, and not with the indigenous bacterial flora.

A detailed description of the area will be given in ALLANSON'S publication of biological and chemical results (3).

From November/December, 1955 onwards, regular monthly samples for bacteriological analysis were collected from 27 sampling stations at suitable points along the courses of the Jukskei River and its main tributaries, the Zandfontein, Braamfontein and Klein Jukskei Rivers. Sampling was discontinued at the end of the dry winter season in August, 1958. Thus the period under investigation covered three rainy summer seasons and three dry winter seasons.

More than 900 samples were collected and analysed, and more than 5,500 individual results were recorded.

II. ORGANISATION

For the purposes of the survey and for the presentation of its results, sampling stations have been subdivided into four groups. The first group comprises the upper part of the Jukskei River from its source in the Bezuidenhout Valley area in Johannesburg to its confluence with the little stream from the lagoons at Modderfontein. The second group consists of the sampling stations along the courses of two tributaries from the Eastern and North Eastern areas of Johannesburg, the Zandfontein and the Braamfontein Rivers, both of which receive sewage effluents and will be referred to as the "sewage streams". The third group covers the Klein Jukskei River from its head streams to its confluence with the Jukskei River. The Klein Jukskei River does not receive sewage and/or industrial effluents, and therefore presents the picture of a comparatively clean natural river and serves as a basis for comparison. The fourth group comprises the lower reaches of the Jukskei River from Leeuwkop Prison Farm to the Hartebeespoort Dam. Although the Jukskei River joins the Crocodile River before it reaches the Hartebeespoort Dam, the lower part of the Crocodile River has been regarded as a continuation of the Jukskei River. The attached map (Fig. 1) shows the position of the sampling stations.

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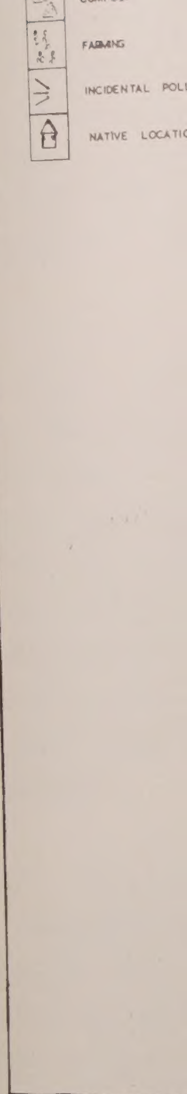

III. METHODS

Samples were collected in monthly intervals from all stations, usually in three groups covering three distinct areas of the river system within three successive days. On arrival at the laboratory, samples were refrigerated over night and inoculated for examination early on the following morning, i.e. within less than 24 hours after collection. Intervals between collection and inoculation for examination varied from 19 to 21 hours. Sampling and inoculating procedures were uniform throughout the period of the survey.

Routine methods of bacteriological analysis used by the Bacteriological Division of the National Institute for Water Research have been employed throughout. These methods have been discussed in detail elsewhere (4). The particular set of determinations adopted for routine purposes has been found to be especially well suited for the analysis of sewage effluents and of natural water courses which receive the final effluents from sewage purification plants. Its value has been tested in another ecological study of a Transvaal river system (5).

(i) Total Count.

„Total count" refers to the number of colonies of micro-organisms on a poured plate of nutrient agar after 48 hours' incubation at 37°C. The count is relative, and can obviously only refer to organisms which are capable of growing under the exactly defined conditions of the test. Since the main interest of the study centered on organisms which were introduced into the stream from outside sources, incubation of similarly prepared plates at 20°C., which would have shown, to a certain extent, the indigenous bacterial population of the stream, was not considered necessary at the time the survey was planned.

(ii) Lactose Broth.

Inoculation of 1 ml. portions of decimal dilutions of the original sample into lactose broth provides the Most Probable Number (M.P.N.) of organisms capable of fermenting lactose with the production of gas within a specified period of incubation at 37°C. The organisms determined quantitatively by this method are members of the coliform group and *Clostridium* spp. mainly, but also include aerobic sporeforming bacteria and the paracolon group. By observation of the tubes after 24, 48, and 72 to 96 hours a definite distinction between lactose fermenters generally and „slow" lactose fermenters can be achieved. The figures reported here include all lactose fermenting organisms.

(iii) Brilliant Green Bile Lactose Broth.

Inoculation of the sample, as described above, into brilliant green bile lactose broth provides after 48 hours' incubation at 37°C. the M.P.N. of organisms belonging to the coliform group irrespective of their source of origin, i.e. *Escherichia coli* and other *Escherichia* spp. as well as *Aerobacter aerogenes* and the so-called intermediate group.

(iv) MacConkey Broth.

Inoculation of the sample into MacConkey broth and 48 hours' incubation in a waterbath at a constant temperature of 44.5°C. provides the M.P.N. of *Escherichia coli* only. Positive MacConkey tests under these conditions are practically diagnostic for faecal *Escherichia coli* Type I.

(v) Koser's Citrate Medium.

Inoculation into Koser's citrate medium and incubation at 37°C. for 48 hours provides the M.P.N. of organisms which, although being members of the coliform group, are not necessarily of faecal origin, and which may give rise to false or exaggerated reactions when brilliant green bile broth alone is used for the quantitative determination of the extent of faecal pollution. Koser's citrate medium is commonly used in the further differentiation of the coliform group when testing for IMVIC reactions, being a specific medium for the identification of members of the coliform group which are non-faecal, or usually non-faecal in origin, and which are capable of utilising an ammonium salt, usually sodium ammonium phosphate, as the sole source of nitrogen, and sodium citrate as the sole source of carbon.

(vi) BAGG (Buffered Azide Glucose Glycerol) Broth.

The use of buffered azide glucose glycerol broth provides a means of demonstrating the presence of enterococci, *Streptococcus* spp. of faecal origin; it permits their quantitative estimation, and serves as additional proof of faecal contamination, particularly, in the author's opinion, of what could be termed "delayed" pollution. This definition will be discussed later.

The significance of the results obtained by these methods, and their interpretation in the light of the available information will be discussed later.

IV. PRESENTATION OF RESULTS

All results are presented in tables of figures which usually refer to the Most Probable Number (M.P.N.) of organisms per milliliter of original sample in the case of liquid media, with the exception of the figures for the Klein Jukskei River, where bacterial numbers are given per 100 ml. of original sample. In the case of total counts on nutrient agar, the figures are direct counts. All figures are geometrical means of four to six samples per sampling station per season; the total number of samples for each individual sampling station for the whole period of the survey varied from 24 to 36. The calculation of geometrical means excludes the effect of extremely high or extremely low individual results, which would not be the case if arithmetic means had been used.

The number of samples from each individual sampling station for both seasons separately was not sufficient to render the application of statistical methods of analysis and evaluation advisable. Most statisticians agree that more than 30 results are usually required for statistical treatment. Although over the complete period of the survey more than 30 samples were collected from each individual sampling station, these samples had to be subdivided into dry and rainy season samples on account of marked seasonal variations.

The results presented in the form of tables have then been used to construct graphs for the different groups of sampling stations. The results obtained in the five differential liquid media have been plotted on logarithmic paper for the stations within each group, and separately for rainy and dry seasons.

The same figures have been used to construct histograms showing the percentage distribution of three components of the bacterial population as determined quantitatively by the use of the respective liquid media. The interpretation of these histograms will follow in a special section after the description of the sampling stations and the discussion of the numerical results.

Again, some of the figures presented in the tables have been used in the graphical presentation of the relation of certain components of the bacterial population to flow and rainfall. These measurements are, however, only available for a limited number of stations.

A final group of graphical presentations shows the effect of self-purification along the course of the Jukskei River from Bezuidenhout Valley to the Hartebeespoort Dam.

Average figures for all stations and for the whole period under investigation are presented in Table I.

TABLE I

Jukskei—Crocodile System. All Sampling Stations. Total Averages over Period of Investigation, Expressed as Geometrical Means of Most Probable Numbers per Milliliter.

Station	Total Count	Lactose Fermenters	Coliform Group	Faecal Streptococci	Citrate Utilisers	Faecal E. coli
First Group: The Upper Jukskei River.						
1.	324,080	824	580	41	158	115
2.	314,400	1,452	907	81	495	322
3.	128,300	769	533	47	253	170
4.	182,600	528	570	17	150	79
5.	183,500	693	497	67	124	101
6.	103,500	228	124	12	37	27
8.	93,300	213	102	12	34	34
Second Group: The Sewage Streams: The Zandfontein River.						
10.	68 790	133	68	4	55	7
11.	235 700	1,416	841	39	373	299
12.	61 930	147	53	4	70	6
9C.	83 280	116	54	2	29	14
Second Group: The Sewage Streams: The Braamfontein River.						
16.	9,680	15	8	2	26	1
15.	317,300	785	540	15	337	80
14.	176,800	619	559	33	221	64
13.	98,190	203	125	12	58	27
9C.	83,280	116	54	2	29	14
Third Group: The Klein Jukskei River.						
17.	5,620	11	3	2	11	1
18.	7,190	9	2	1	12	1
19.	8,590	10	5	2	9	2
19A.	7,785	13	6	1	17	2
20.	14,230	19	9	1	33	2
Fourth Group: The Lower Jukskei River.						
9A.	148,100	149	78	4	71	9
9B.	104,700	157	81	5	54	12
9D.	107,400	357	242	8	74	30
20A.	63,430	192	107	4	81	13
21.	12,900	14	5	1	11	1
22.	26,680	23	11	1	29	2
23.	15,070	8	6	1	13	1

V. DEFINITION OF POLLUTION

"Pollution" here means, unless otherwise stated, pollution from sewage effluents, or direct incidental faecal pollution, or heavy organic contamination which may, in part at least, be of faecal origin.

VI. DESCRIPTION OF STATIONS AND RESULTS

1. The First Group: The Upper Jukskei River.

The first group of sampling points, Stations 1 to 8, extend along the upper reaches of the Jukskei River, from its source in the Bezuidenhout Valley area of Johannesburg to its confluence with the little stream from the lagoons at Modderfontein. The results of bacteriological analysis for rainy summer seasons and dry winter seasons respectively have been presented in Table II.

TABLE II

Jukskei River, Upper Reaches (Stations 1 to 8). Averages for Rainy Summer Seasons. Expressed as Geometrical Means of Most Probable Numbers of Organisms per Milliliter.

Station	Total Count	Lactose Fermenters	Coliform Group	Faecal Streptococci	Citrate Utilisers	Faecal E. coli
1.	935,800	2,475	1,884	59	1,565	490
2.	606,100	1,752	983	34	1,874	321
3.	220,900	916	606	30	870	178
4.	278,500	1,047	856	15	1,237	113
5.	303,900	1,251	1,002	88	895	187
6.	176,400	255	161	13	177	33
8.	162,800	441	182	22	405	70
			Averages for Dry Winter Seasons (otherwise as above).			
1.	112,800	254	168	29	111	24
2.	162,900	1,218	842	191	165	322
3.	77,270	660	468	72	86	162
4.	127,900	498	408	18	33	58
5.	114,800	511	266	54	21	59
6.	58,480	201	92	10	32	21
8.	51,520	93	53	7	3	14

(i) Station 1: The Jukskei River above the Cyrildene Bridge in Bezuidenhout Valley.

Station 1 is situated on the outskirts of the City of Johannesburg; the river drains an area which on the South bank is predominantly residential and in part industrial, the industries consisting of laundries

and dry cleaning works, a gramophone record pressing factory, and similar "light" industries, whereas on the North bank there are market gardens under extensive cultivation.

The sampling point is subject to widely varying types of pollution which, as a whole, is severe, but the diversity of the contributing factors makes it extremely difficult to define individual effects clearly. The effects of the industrial effluents, which may reach the river directly, can not be assessed by the bacteriological methods employed. During the rainy season considerable quantities of run-off from market gardens must reach the river, and the possibility can not be excluded that some of these vegetable fields are manured with fresh human faeces. There is, to a certain extent, direct faecal pollution due to the rather uninhibited defaecatory habits of Africans, who regard any stream as a convenient natural latrine. There is, on the other hand, no direct pollution by sewage or sewage effluents. On the basis of the total count alone, the station would have to be classified as polysaprobic during the rainy season, but results from other differential determinations do not appear to be in full agreement with this definition. Moreover, from the ratio between *Escherichia coli* and faecal streptococci, which falls below 1 during the dry season, it appears that the additional faecal pollution of the river is due to seepage from heavily manured lands rather than to fresh direct faecal pollution; the pollution is "delayed". This conception will be explained later.

(ii) Station 2: The Jukskei River at Gilloolie's Farm, below Bruma Sewage Disposal Works.

The drainage area of Station 2 is recreational and includes a week-end picnic spot. The grounds are municipal property and are used for cattle grazing. Approximately one mile above the sampling point, the effluent from the Bruma Sewage Disposal Works is discharged into the river, more often than not insufficiently settled effluent from an activated sludge plant. Under the circumstances, the water can not be considered as suitable for recreational purposes by any standard.

There is some improvement in bacteriological quality between Stations 2 and 3, in spite of the fact that between these two sampling points the effluent from the Sandringham Sewage Disposal Works reaches the river. Occasional sampling immediately below the outfall of the sewage works has shown, however, that no appreciable further deterioration in bacteriological quality results.

(iii) Station 3: The Jukskei River below the Edenvale Bridge on the Modderfontein Road, above Edenvale Hospital.

(*iv*) *Station* 4: *The Jukskei River below Lombardy East.*

There is a slow progressive improvement in bacteriological quality from Station 2 to Station 3, which continues towards Station 4. From Table II it will be seen that faecal pollution decreases progressively from Station 1 to Station 4, although during the rainy season the effect of run-off makes itself felt in the increase in total count and in the figures for the coliform group and citrate utilisers. The expectation, however, that run-off from densely populated native areas, like Alexandra Township, which drains in part towards the Juskei River above Station 4, should supply contributions of considerable magnitude to the faecal pollution of the river, is therefore not substantiated by the actual results of this survey. Incidental faecal pollution, which undoubtedly exists, is not so severe as to affect conditions in the river materially.

(*v*) *Station* 5: *The Jukskei River above Northlea, below the Composting Plant of the Alexandra Township Health Committee.*

The drainage area is sparsely populated. Throughout the year the river receives seepage, and during the rainy season, direct run-off from a so-called composting plant at which unsuccessful attempts are made to convert a mixture of domestic refuse, manure and night soil into compost by the addition of saw dust, wood shavings and similar materials, and subsequent storage in pits or "cells". Both during the rainy season and during the dry season faecal contribution from this plant is considerable, and far larger in extent than the simultaneous contribution of organisms of possible non-faecal origin. During the dry season the ratio between *Escherichia coli* and enterococci falls below 1, indicating that pollution is of the "delayed" type. The probability of incidental faecal pollution at Station 5 is low, and occasional human activities, like the recovery of sand from the river, may result in increases in the total count and in the number of citrate-utilisers, but not in an increase in the faecal components of the bacterial population.

The possibility of heavy incidental faecal pollution directly from Alexandra Township can be excluded; evidence of heavy faecal pollution has been found only below the composting plant, but not above, in the drainage area of the township.

A few hundred yards below the composting plant, where the river has to some extent recovered from the effects of the composting plant, sewage effluent from social institutions at Northlea and Wedge Farm reach the river. But the sewage is treated in septic tanks and French drains, and the effluent is used for irrigation of vegetable and flower gardens. On reaching the river eventually, it does not contribute to its pollution at all.

(vi) Station 6: The Jukskei River at Buccleugh Bridge.

The drainage area is sparsely populated, a peri-urban residential area with some agricultural activity. The probability of incidental faecal pollution is low. The station usually presents the picture of a fairly clean stream; the effects of previous heavy pollution have practically been overcome.

(vii) Station 8: The Jukskei River at the Confluence with the Modderfontein Stream.

Conditions slightly deteriorate again between Stations 6 and 8 during the rainy season, whereas during the dry season further slow improvement takes place. Deterioration during the rainy season is probably due to the overflow from the lagoons and dams at Modderfontein where, apart from industrial effluents, in all probability effluents from a sewage purification plant, or even raw sewage, are discharged and stored. There is practically no possibility of incidental faecal pollution. It does not appear that the industrial effluents from Modderfontein exert any appreciable influence on the bacterial population of the river.

In Fig. 2 and 3, the results of bacteriological analysis, except total counts, have been presented graphically for the rainy and dry season respectively, and these graphs are self-explanatory.

Fig. 2 shows conditions between Stations 1 and 8 during the rainy season when, on the whole, self-purification functions satisfactorily and progressively as far as the reduction in bacterial numbers is concerned. It also shows the increases in localised faecal pollution at Stations 5 and 8, the reasons for which have been given before. It also shows an increase in the coliform group at Stations 4, but this increase is not repeated in a corresponding increase in the faecal components of the bacterial population, and the expected increase in faecal pollution by run-off from a densely populated African township has not been established on the basis of the results obtained.

Fig. 3 shows conditions between Stations 1 and 8 during the dry season. After an initial increase in the bacterial population at Station 2, due obviously to the discharge of sewage effluent into the river, self-purification proceeds satisfactorily and progressively, with the exception of an increase in the number of faecal streptococci at Station 5, due to seepage of some of the material treated at the composting plant, and an increase in citrate-utilisers at Station 6, for which no explanation can be offered.

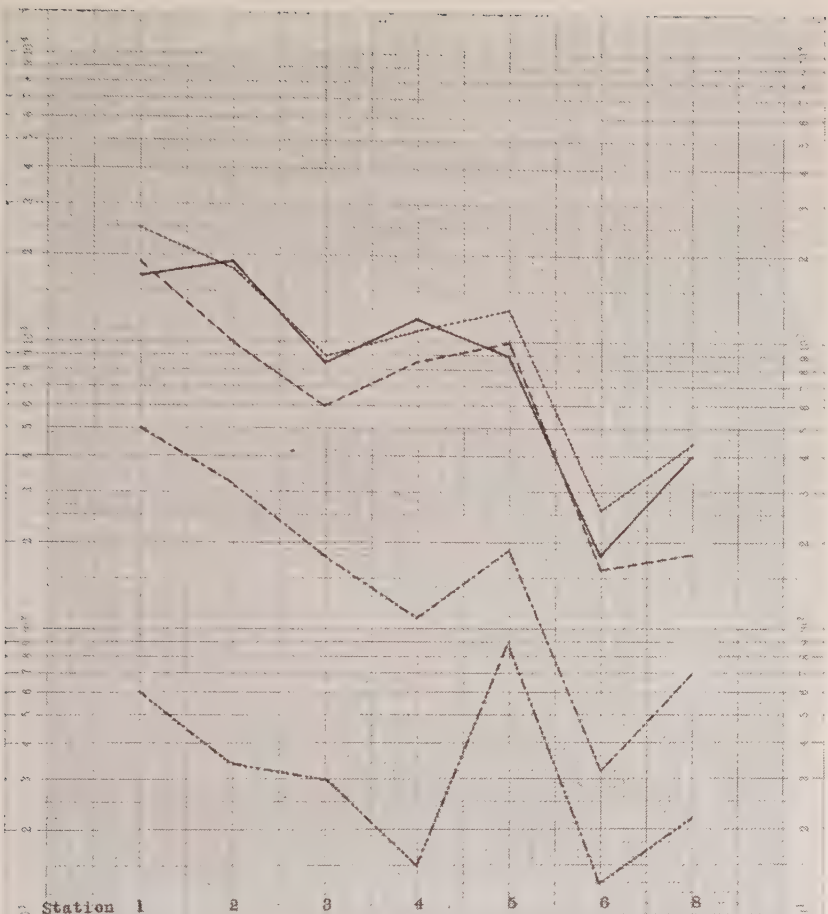

Fig. 2 : Jukskei, Upper Reaches, Rainy Seasons.

Lactose Fermenters
Coliform Group
Citrate Utilisers
Faecal E. coli
Faecal Streptococci

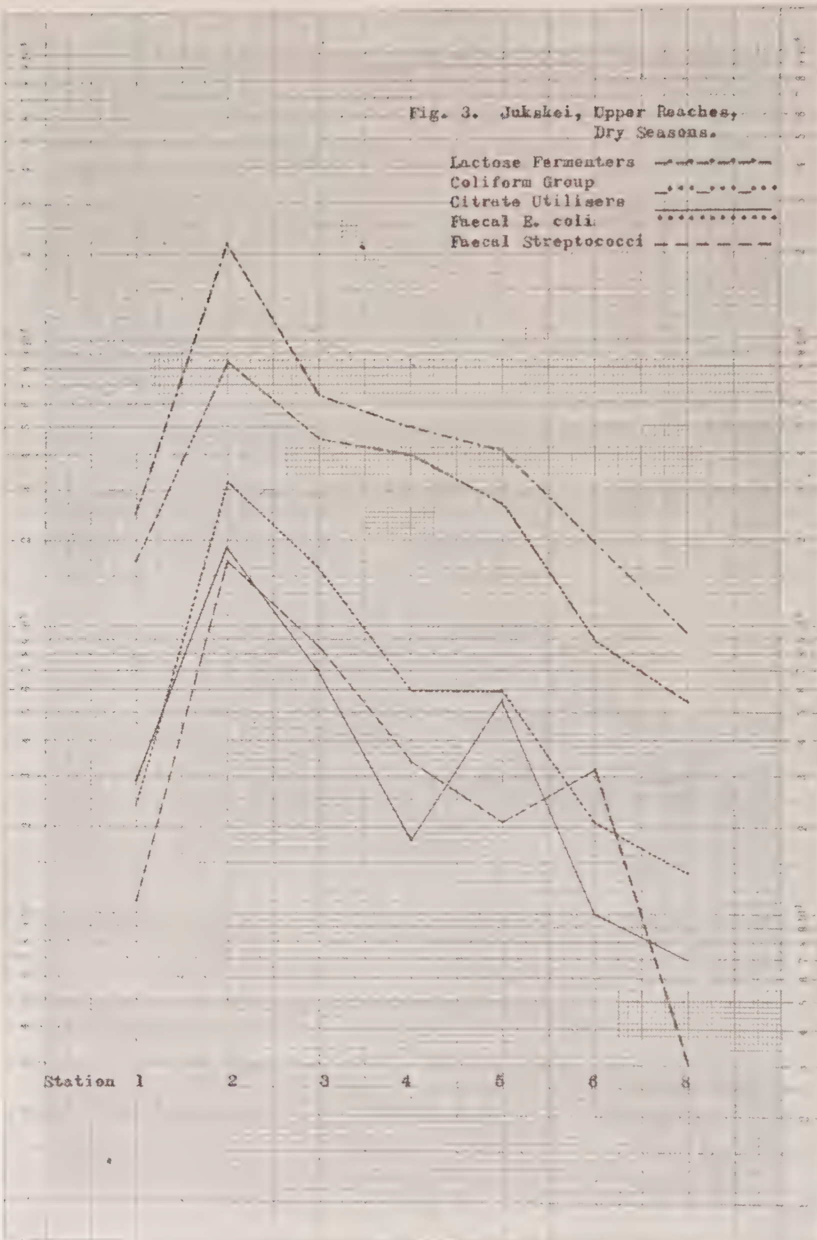
Fig. 3. Jukskei, Upper Reaches, Dry Seasons.
Lactose Fermenters
Coliform Group
Citrate Utilisers
Faecal E. coli
Faecal Streptococci
Station 1
2
3
4
5
6
8

2. The Second Group: The Sewage Streams.

A. The Zandfontein River.

Results from the four sampling points along the course of the Zandfontein River show particularly clearly the effect of sewage pollution on a stream which is originally fairly satisfactory in bacteriological quality, and they also show the effect of self-purification which takes places in the lower reaches of the river before it reaches the Jukskei River at the Leeuwkop Prison Farm. Additional incidental pollution gains access to the river within the grounds of the farm, and this finds expression in increases in bacterial numbers.

The results for the rainy and dry seasons respectively have been tabulated in Table III.

TABLE III

The Sewage Streams: The Zandfontein River. Averages for Rainy Summer Seasons, Expressed as Geometrical Means of Most Probable Numbers of Organisms per Milliliter.

Station	Total Count	Lactose Fermenters	Coliform Group	Faecal Streptococci	Citrate Utilisers	Faecal E. coli
10.	108,400	237	138	4	381	7
11.	352,400	2,399	1,784	45	2,189	914
12.	101,600	271	156	11	416	16
9C.	141,800	181	232	11	477	37
		Averages for Dry Winter Seasons (otherwise as above).				
10.	39,850	74	38	4	9	7
11.	153,300	800	314	32	64	114
12.	38,980	86	156	1	12	2
9C.	47,090	77	22	1	4	4

(i) *Station* 10*: Zandfontein River above the Glenhove Road Bridge.*

The drainage area comprises residential suburbs and a golf course. Incidental faecal pollution is, to some degree, always evident, particularly during the dry season and at low flow rates when the canalised river bed is easily accessible. Faecal pollution is practically constant throughout the year, and is not subject to seasonal variations.

(ii) *Station* 11*: Zandfontein River at the Waverley Bridge, Bramley.*

The drainage area is purely residential. The topography of the region makes incidental faecal pollution improbable. Less than one mile above the sampling point the final effluent from the Cydna Sewage Disposal Works is discharged into the river. There are seasonal variations in the bacterial population, but it remains obvious that the main effect is due to sewage effluent.

(iii) Station 12: Zandfontein River at the Rivonia Bridge.

The drainage area is a sparsely populated peri-urban residential area with some agricultural activity, mainly in the form of small-holdings. The river has to a large extent recovered from the effects of sewage pollution. There are increases in the faecal components of the bacterial population during the rainy season, probably due to incidental direct pollution.

(iv) Station 9C: Zandfontein River above the Confluence of the Combined Zandfontein and Braamfontein Rivers with the Jukskei River.

The drainage area covers part of the Leeuwkop Prison Farm and surrounding agricultural lands. Incidental faecal pollution appears possible, but it does become obvious from the results obtained. During the dry season, lactose fermenters, the coliform group and citrate-utilisers are further reduced in numbers; faecal streptococci remain at the same level, and *Escherichia coli* increases slightly. During the rainy season, on the other hand, the main rise in numbers occurs in the coliform group and the citrate-utilisers, again indicating that run-off, even if incidental pollution is to be expected, does not add to the faecal components of the bacterial population. The figures obtained only prove that incidental pollution is present, and it must be assumed that it is direct and more or less consistent throughout the year.

The numerical results have been plotted and are presented graphically in Fig. 4. The figures for the rainy and dry seasons respectively are plotted next to each other.

Both graphs clearly show the effect of the discharge of sewage effluent above Staiton 11. They also show that there is very little variation in the numbers of the faecal components of the population, and that an appreciable contribution to faecal organisms by run-off from a built-up European area is excluded. The graphs also indicate that self-purification takes place between Stations 11 and 12, and show the occurence of additional pollution at Station 9C, additions which are more varied during the rainy than during the dry season. It must be assumed, therefore, that direct incidental faecal pollution is a contributory factor at any time of the year, and that run-off during the rainy season does not contribute faecal organisms in appreciable numbers.

B. The Braamfontein River,

Along the course of the Braamfontein stream the picture is not quite as clear as on the Zandfontein River. Station 16 was, at the beginning of the survey, practically unpolluted, but has to some extent deteriorated since, mainly under the influence of increased

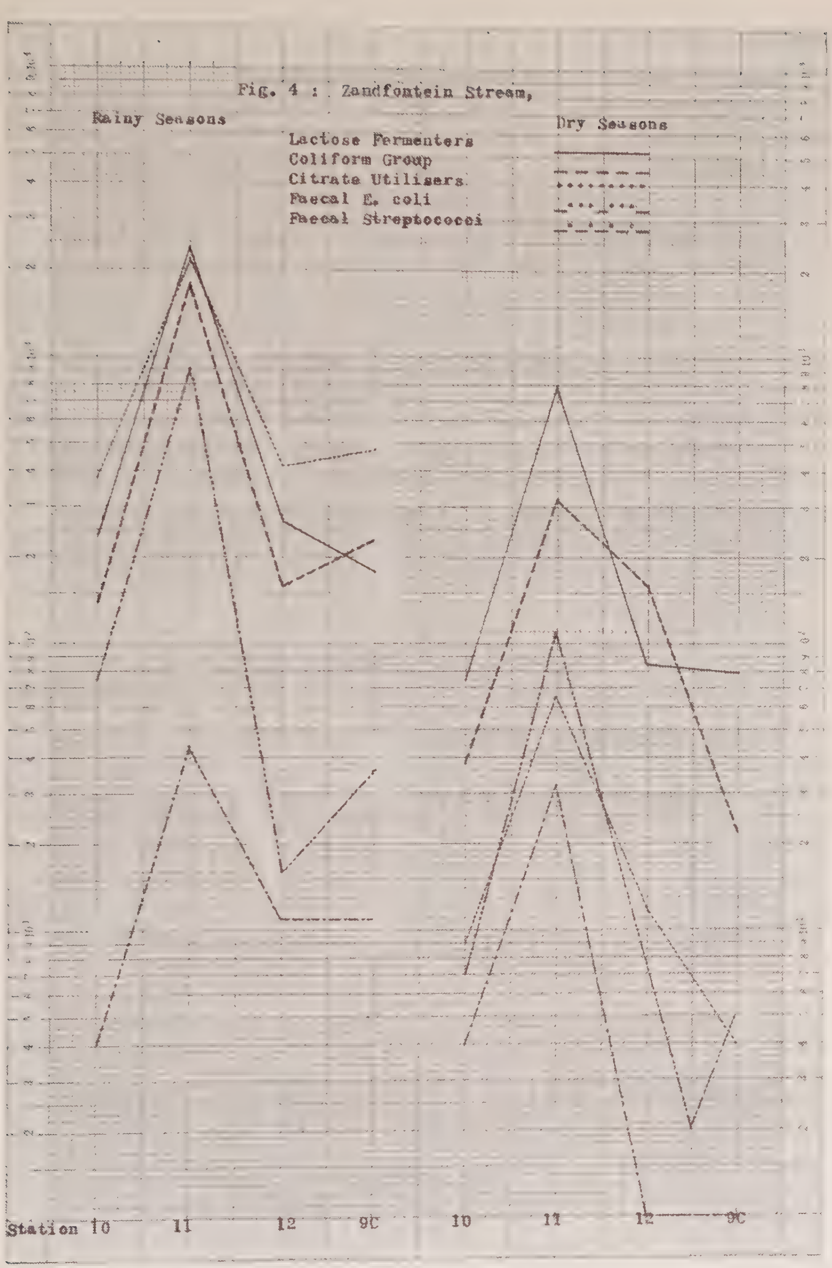

Fig. 4 : Zandfontein Stream,
Rainy Seasons
Dry Seasons
Lactose Fermenters
Coliform Group
Citrate Utilisers
Faecal E. coli
Faecal Streptococci
Station 10
11
12
9C
10
11
12
9C

human activity in the drainage area. Station 15, which is in no way affeced by the discharge of sewage effluents, shows a far larger bacterial population than Station 14, where one would expect to find a definite expression of the effect of the discharge of sewage effluent. Although Station 14 is far from satisfactory from the bacteriological point of view, conditions are better than at Station 15, in spite of the fact that between these two sampling points the final effluent from the Delta Sewage Disposal Works used to reach the river for most of the period under investigation. Station 13, however, shows again very clearly the effect of self-purification over a comparatively short distance. It may be mentioned that a tannery, which is situated between Stations 14 and 13, and from which effluents must reach the river, has no appreciable effect upon the river's bacteriological quality, apart perhaps from a very slight manifestation of incidental faecal pollution, which is due to direct contamination from the African labourers' quarters.

The numerical results from the sampling points along the course of the Braamfontein River have been tabulated in Table IV.

TABLE IV

The Sewage Streams: The Braamfontein River. Averages for Rainy Summer Seasons, Expressed as Geometrical Means of Most Probable Numbers of Organisms per Milliliter.

Station	Total Count	Lactose Fermenters	Coliform Group	Faecal Streptococci	Citrate Utilisers	Faecal E. coli
16.	14,370	40	18	6	151	3
15.	670,100	2,587	2,894	48	2,863	407
14.	274,100	1,384	1,214	44	1,030	134
13.	234,100	710	521	93	457	83
9C.	141,800	181	232	11	477	37
Averages for Dry Winter Season (otherwise as above).						
16.	5,950	5	3	1	5	1
15.	157,900	258	89	5	47	14
14.	110,500	317	215	25	40	32
13.	38,710	52	24	3	7	10
9C.	47,090	77	22	1	4	5

(*i*) *Station* 16: *The Braamfontein River at the Waterval Bridge.*

The drainage area was set aside for residential development and, when the survey started, still unpopulated. It is now being built up, and excavating and building activities are in progress. With increasing human activity, the river has been slowly deteriorating in bacteriological quality. There is a distinct possibility of incidental faecal pollution.

(*ii*) *Station* 15: *The Braamfontein River at the Parkhurst Bridge.*
The drainage area is mainly residential and includes a complex of sportsground. Whereas the East bank of the river is densely populated the West bank does not fall within the municipal boundary and is not connected to the City's sewerage system. There is a distinct possibility, therefore, that seepage from French drains and septic tanks plays an important part in the pollution of the river. A further contributory factor is the fact that during weekends part of the drainage area, mainly below the actual sampling point, however, serves as a gathering ground for urbanised Africans, and that there is a possibility of heavy incidental pollution. During 1956/57 extensive earth-moving operations were in progress, and the total count rose to more than 500,000 organisms per milliliter. But whereas during the initial stages of the survey hardly any faecal pollution was demonstrable, in the course of time faecal pollution increased, mainly during the rainy season, to figures which were higher than those determined for the sewage-polluted Station 14. Station 15 is, therefore, one instance where a detailed study of local conditions is required, and an example of the difficulty encountered in trying to establish sources of pollution.

(*iii*) *Station* 14: *The Braamfontein River at the Craighall Road Bridge.*
The dam above the bridge, where samples were taken, received the effluent from the Delta Sewage Disposal Works. Conditions in the mud deposits along the banks of the dam were usually anaerobic. Particularly during the dry season, faecal pollution is more pronounced here than at any other sampling point along the course of the Braamfontein stream, and it is quite obvious that under dry weather conditions, when the possible effect of run-off is excluded, the effect of the discharge of sewage effluent into the stream becomes predominant.

(*iv*) *Station* 13: *The Braamfontein River at the Bryanston Bridge.*
Station 13 is very similar to Station 12 on the course of the Zandfontein River. The topography is more or less the same, and distances between Stations 11 and 12 on the one hand, and Stations 14 and 13 on the other hand, are about equal. But whereas self-purification is fairly satisfactory between Stations 11 and 12 on the Zandfontein stream, it is not quite as good between Stations 14 and 13. In general, conditions along the Braamfontein stream are less satisfactory then along the Zandfontein River.

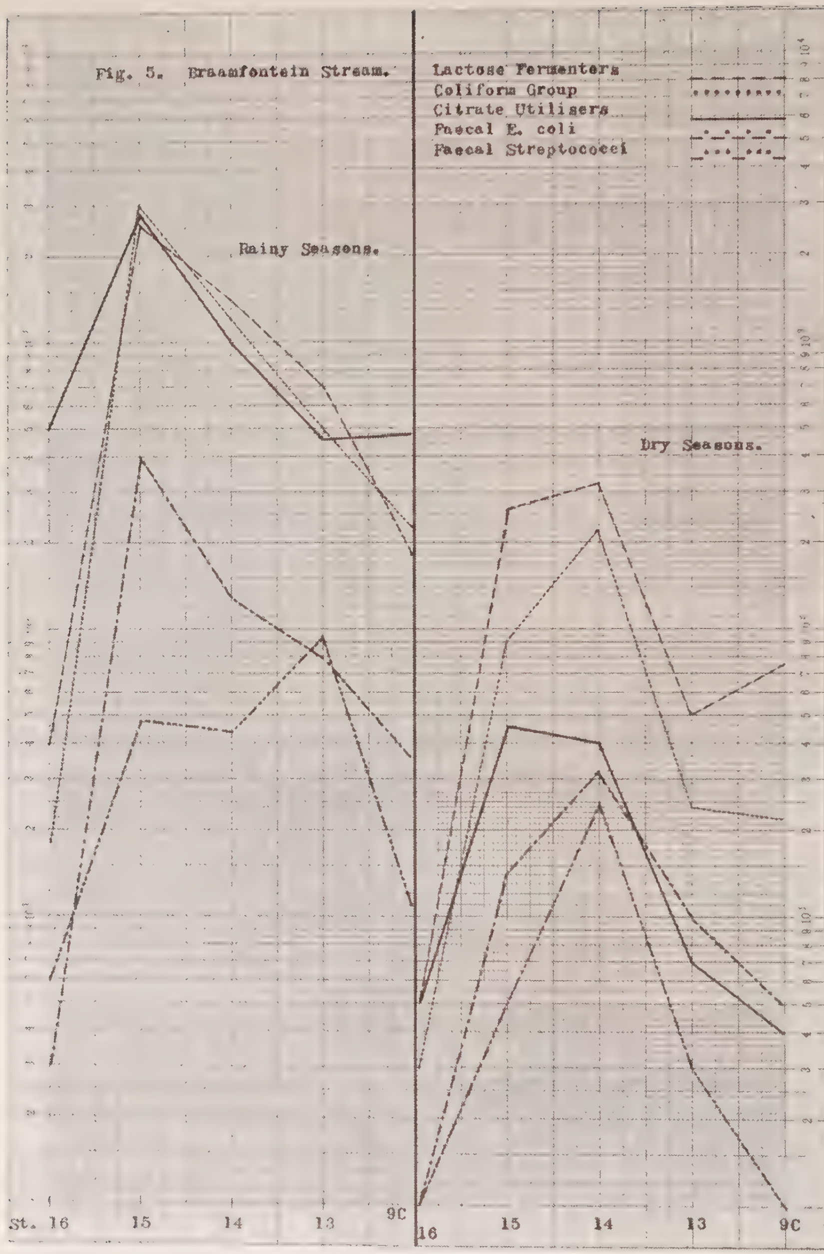
Fig. 5. Braamfontein Stream.
Lactose Fermenters
Coliform Group
Citrate Utilisers
Faecal E. coli
Faecal Streptococci
Rainy Seasons.
Dry Seasons.
St. 16
15
14
13
9C
16
15
14
13
9C

(*v*) *Station 9C:*

This sampling point has been dealt with in the preceding section on the Zandfontein River.

The results from the sampling points along the course of the Braamfontein River have been plotted in Fig. 5. Results for rainy and dry seasons respectively are shown next to each other.

Comparing Fig. 4 and Fig. 5, the difference in conditions is striking. Whereas along the Zandfontein stream there is one peak of maximum faecal pollution at Station 11, obviously due to the discharge of sewage effluent from Cydna, in the Braamfontein River faecal pollution can be attributed to a number of different factors, as outlined above. From the graphical presentation it becomes evident that in the Braamfontein stream the effects of pollution are more persistent in magnitude and in distance, and that self-purification is retarded. This is remarkable since the initial load of faecal pollution, expressed in the number of faecal organisms, is higher in the Zandfontein than in the Braamfontein stream.

During the rainy season, the maximum of faecal pollution, as measured by the numbers of *Escherichia coli*, occurs at Station 15, due only to incidental pollution from various sources, and not to the direct effect of sewage effluent. At Station 13, there is usually a higher count for faecal streptococci than for *E. coli*. The reason for this may be that Station 13 serves as a watering place for cattle, and that direct contamination with manure occurs. *Streptococcus bovis* probably causes the same reactions in BAGG broth as *Streptococcus* spp. of human origin.

During the dry season, however, the picture changes, and the maximum faecal pollution occurs at Station 14 as would be expected in view of the circumstances.

3. The Third Group: The Klein Jukskei River.

The five sampling points along the course of the Klein Jukskei River present the picture of a reasonably clean natural stream throughout. The results obtained indicate only very slight incidental pollution. Water at Station 18, by the way, is evidently used by the African inhabitants of a near-by location for domestic purposes, without apparent ill-effects. The results from the Klein Jukskei River clearly show the decrease in bacterial numbers during the dry season when there is no run-off, and when the introduction of foreign organisms into the river is excluded. The results also indicate that, in spite of an occasional high total count, there is no reason to assume pollution to a serious extent on the basis of just this one criterion. Pollution can only be accurately assessed by the quantitative determination of organisms which are not the natural and normal inhabitants of the

water courses in question, but which have been introduced by sewage, sewage effluents, or direct faecal pollution.

The results for the rainy and dry seasons respectively have been tabulated in Table V. Figures refer to the number of organisms per 100 milliliters of the original sample.

TABLE V

The Klein Jukskei River. Averages for Rainy Summer Seasons, Expressed as Geometrical Means of Most Probable Numbers of Organisms per 100 Milliliters.

Station	Total Count	Lactose Fermenters	Coliform Group	Faecal Streptococci	Citrate Utilisers	Faecal E. coli
17.	1,190,000	3,390	1,100	640	9,970	160
18.	1,128,000	3,470	950	500	8,930	620
19.	1,767,000	2,490	2,140	330	5,620	290
19A.	1,380,000	2,000	1,710	110	10,740	410
20.	2,963,000	4,250	1,560	180	17,420	270
Averages for Dry Winter Seasons (otherwise as above).						
17.	265,700	390	80	80	130	30
18.	439,400	210	30	20	120	30
19.	396,600	400	120	100	140	90
19A.	457,400	920	240	50	330	40
20.	648,500	920	260	80	710	200

(*i*) *Station* 17*: Klein Jukskei River at the Klipfontein Bridge.*

The drainage area is unpopulated, consisting mainly of grazing lands and cultivated ground. Incidental pollution by cattle is usually evident, and may account for the occurrence of faecal streptococci in predominance over *E. coli;* similar observations have been made at Station 13.

(*ii*) *Station* 18*: Dam above African location.*

The drainage area is sparsely populated and mainly agricultural; a farm yard and homestead are included in the immediate vicinity. The water in the dam is used for domestic purposes by the inhabitants of an African location immediately below the dam. The possibility of incidental faecal pollution exists, but it has not been possible to obtain evidence of the occurrence of enteric disorders which could be related to the use of the water. The overflow from the dam joins the little stream sampled at Station 17, and together they form part of the head waters of the Klein Jukskei River.

(iii) Station 19*: Weir below the Velskoen Drive-In Theatre at Fontainebleau.*

The drainage area is sparsely populated; there are agricultural smallholdings and market gardens. There is a picnic spot on the river below the actual sampling point, in spite of official warning boards pointing out that he trisk of infection with Bilharziasis exists. There is a slight possibility of incidental faecal pollution.

(iv) Station 19*A:*

This sampling point was established some time after the survey had been started because it was felt that the distance between Stations 19 and 20 was too great, and that an intermediate sampling point on the river was needed. The drainage area is sparsely populated and comprises smallholdings and agricultural lands. Incidental faecal pollution seems to be negligible, although during the rainy season an increase in faecal *E. coli* occurs which is not accompanied by a corresponding rise in the number of faecal streptococci. This seems to indicate fresh faecal pollution rather than the effect of run-off from manured lands.

(v) Station 20*: The Klein Jukskei above the Confluence with the Jukskei River.*

The drainage area consists mainly of grazing and agricultural lands; there are no specific features worth mentioning.

The results from the five sampling points along the course of the Klein Jukskei River are presented graphically in Fig. 6. The figures used for the graphs refer to the Most Probable Numbers of organisms per 100 milliliters of original sample. Results for the rainy and dry seasons respectively have been plotted next to each other.

During the rainy season by far the highest proportion in the bacterial population consists of organisms capable of utilising citrate, which are not necessarily of faecal origin. During the dry season, lactose fermenters are predominant. This reversion in order of predominance indicates that under normal circumstances, i.e. if there is no obvious source of faecal pollution in the immediate drainage area, run-off is mainly responsible for the contribution of organisms which are non-faecal in origin.

During the rainy season, the figures for the five groups of organisms determined remain more or less constant along the whole course of the river; there are no really wide variations from station to station. During the dry season, however, there is a constant progressive increase from the head streams towards the mouth of the river, indicating that, generally speaking, the pollutional load of the river increases progressively, and that there is hardly any evidence of self-

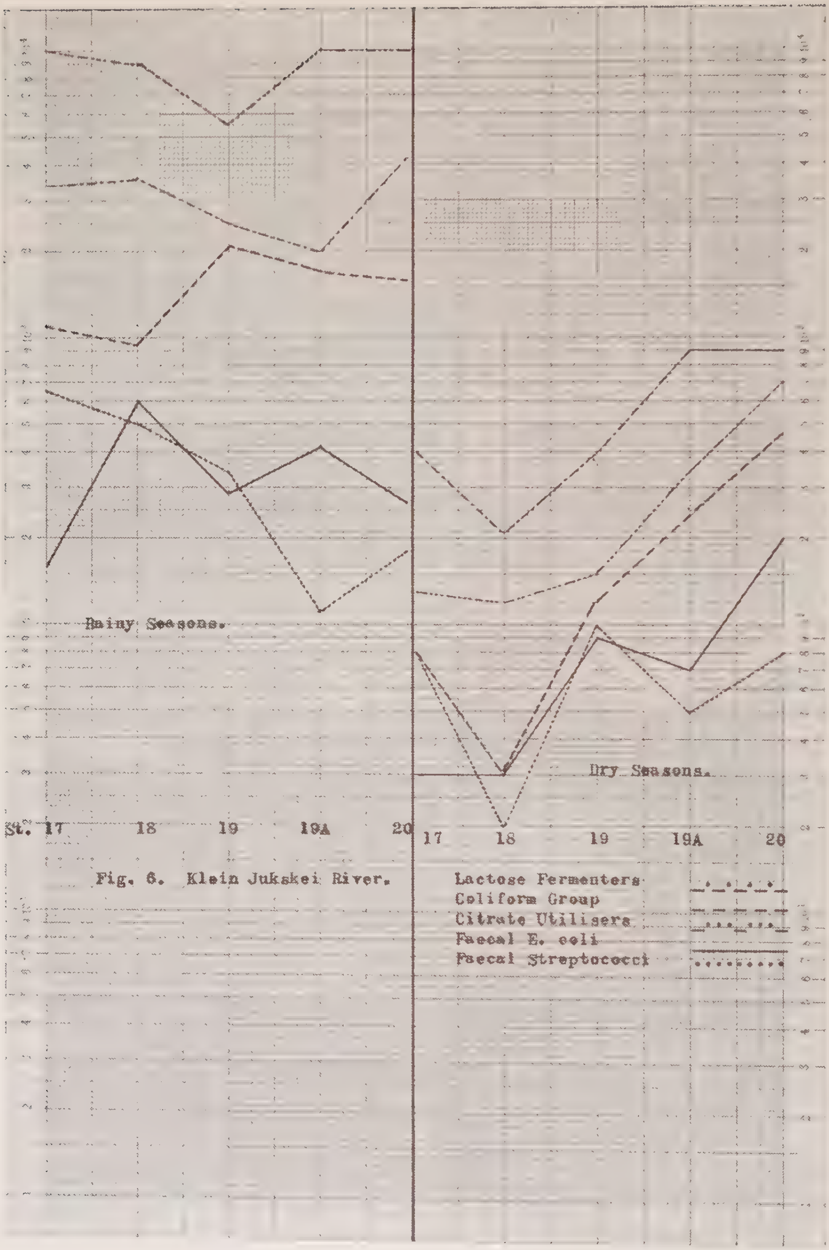

Fig. 6. Klein Jukskei River.

purification. It must be remembered, however, that the pollutional load as such is very small, and that the term selfpurification may not be applicable at all under these circumstances.

4. The Fourth Group: The Lower Jukskei River from Leeuwkop Prison Farm to the Hartebeestpoort Dam.

At the beginning of the survey, no obvious pollution by sewage effluents or by severe direct faecal pollution was expected to occur in this part of the river system. It was supposed that the river would be able to recover more or less completely from the effects of pollution in the upper reaches. It was also expected that no further sources of additional pollution would be encountered in the lower parts of the river. It was found, however, mainly during the latter half of the survey, that additional faecal pollution occurs at Stations 9D and 20A, and to a certain extent at Station 22. It might be possible to ascribe conditions at Station 20A to the use of partially treated sewage effluent for irrigation of lands draining naturally towards the Jukskei River above the sampling point. But it has not been possible to ascertain definitely what factors are operative at Station 9D, and it can only be assumed that the increase in faecal organisms which occurs at Station 9D is due to constant direct pollution, possibly from a French drain, considering that there are hardly any seasonal variations. From Station 20A onwards, however, self-purification proceeds progressively and satisfactorily, with the exception of Station 22 where an increase in *E. coli* occurs during the rainy season which can be attributed to direct faecal pollution from pit privies serving a picnicking area for Whites. There may be other contributing factors, however, which have not been explored.

The results obtained from the seven sampling points along the lower course of the Jukskei River are tabulated in Table VI. Wherever two figures are given next to each other, the one in brackets refers to the number of organisms per 100 milliliters of original sample.

(i) Station 9A: The Jukskei River above the Confluence with the Sewage Streams.

(ii) Station 9B: The Jukskei River below the Confluenve with the Sewage Streams, within the boundary of Leeuwkop Prison Farm.

The drainage area for these two stations are parts of the Leeuwkop Prison Farm which are under extensive cultivation for vegetables and animal feeds. The prison authorities also run a large piggery, and the lands under cultivation are heavily manured, partly with fresh liquid

TABLE VI

The Lower Reaches of the Jukskei River. Averages for Rainy Summer Seasons expressed as Geometrical Means of Most Probable Numbers of Organisms per Milliliter.

Station	Total Count	Lactose Fermenters	Coliform Group	Faecal Streptococci	Citrate Utilisers	Faecal E. coli
9A.	213,200	274	183	18	389	19
9B.	182,900	235	140	11	410	23
9D.	163,400	395	471	6	589	37
20A.	128,200	246	152	10	532	18
21.	36,270	31	21	3 (350)	109	3 (340)
22.	56,760	48	47	2 (175)	230	7 (730)
23.	41,390	39	30	1 (130)	92	2 (230)
			Averages for Dry Winter Seasons (otherwise as above).			
9A.	85,800	71	28	1 (82)	9 (895)	4 (388)
9B.	62,610	93	42	2 (242)	6 (620)	5 (554)
9D.	62,850	313	144	9 (888)	17	25 (2511)
20A.	35,160	147	65	2 (204)	14	11 (1067)
21.	4,155	7 (682)	2 (158)	1 (43)	1 (153)	1 (83)
22.	9,745	10 (958)	2 (237)	1 (24)	2 (250)	1 (39)
23.	5,105	2 (235)	2 (174)	1 (20)	2 (199)	1 (16

manure, and partly with dried and composted materials. The banks of the river are subject to heavy direct incidental pollution from African prisoners who are put to work in the grounds of the establishment. Station 9A is in slowly moving deep water above the confluence with the sewage streams, under big trees and with heavy marginal vegetation both of which contribute to the organic waste material reaching the river directly. Station 9B is below the actual confluence, in comparatively shallow fast running water with a stony bottom. At both stations figures are higher for the rainy season, without doubt due to the contribution by run-off which, however, as outlined above, does not only consist of faecal matter of human origin, but of a variety of organic material of plant and animal sources.

(iii) Station 9D: The Jukskei River at Riverside Estate.

The drainage area is sparsely populated; there are farm buildings immediately above the sampling point. The area is under extensive cultivation. Direct faecal pollution as a constant contributory factor throughout the year has to be assumed on the basis of the results obtained.

(iv) Station 20A: The Jukskei River below Diepsloot Farm.

The drainage area is practically unpopulated; it is used, in part,

however, to dispose of partly treated sewage effluent by broad irrigation on contoured lands. Particularly during the rainy season, run-off reaching the river carries faecal pollution which causes an obvious deterioration in the bacteriological quality of its water. Especially after heavy continuous rain the number of *E. coli* increases, and during the period under investigation average figures have increased progressively from 40 to more than 3,000 *E. coli* per 100 milliliters. It appears advisable, therefore, to keep a constant and careful watch on conditions particularly in this specific area after this survey has been completed. It must be remembered that one of the objectives of the survey was to establish standards which are valid and applicable now, but these standards will have to be maintained in the future to avoid drastic deterioration of water quality in the Haitebeestpoort Dam. A major source of direct faecal pollution has moved very much closer to the Dam. With the potential capacity of the sewage treatment and disposal scheme on Diepsloot Farm, which at a later stage will handle all sewage from Eastern and Northern Johannesburg, there exists the risk that in the course of time the Hartebeestpoort Dam will assume the aspects and the functions of a huge oxidation pond in which the sewage of Johannesburg will receive its final treatment, wihtout the benefit of selfpurification over an extended stretch of river which is at the moment still in a position to cope effectively with the pollutional load it has to carry.

Fig. 7 presents the monthly results for faecal *E. coli* at Station 20A for the duration of the survey. Whereas early in 1956, at the height of the rainy season, values were low and even reached zero several times, values for the latter part of 1956 and for 1957/58 are relatively higher, and these higher values have become more persistent. The exceptionally high values for the period May to July, 1957, are due to unusual heavy winter rains.

Between Station 20A and 21 the Jukskei River joins the Crocodile River, but for the purpose of this survey the lower part of the Crocodile River has been considered rather as a continuation of the Jukskei River than as a major river which receives the polluted Jukskei as a tributary.

(*v*) *Station* 21*: Below the confluence of the Hennops with the Crocodile River.*

The drainage area is sparsely populated farming land. At the sampling point, sand is extracted from the river for a commercial concern. In spite of the presence on the spot of an African labour force, there is no evidence of direct faecal pollution for which they could be held responsible.

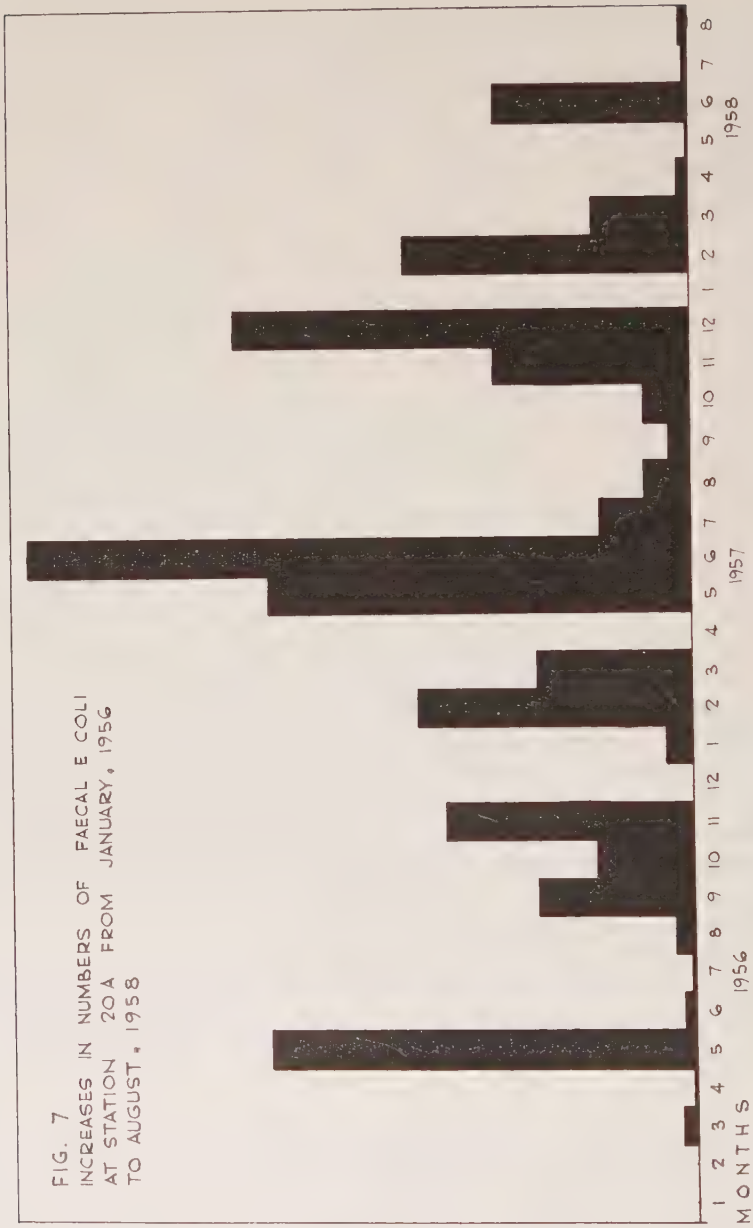

FIG. 7
INCREASES IN NUMBERS OF FAECAL E COLI
AT STATION 20A FROM JANUARY, 1956
TO AUGUST, 1958

(vi) Station 22: The Crocodile River at Pelindaba.

The station has been dealt with in the introduction to this section. The drainage area is "veld", used for grazing purposes to some extent, and serving as a weekend picnic spot. The area is otherwise unpopulated. There is a distinct possibility of spasmodic faecal weekend pollution. There is a definite increase in *E. coli* during the rainy season, and the further decrease in faecal streptococci seems to be somewhat retarded.

(vii) Station 23: Meerhof on the Hartebeestpoort Dam, below the inflow of the Crocodile River.

The drainage area is sparsely populated and serves in part for recreational purposes. The probability of incidental faecal pollution is not very high. On the whole, the bacteriological quality of the water is good, and it could be classified as fit for recreational purposes by any standard, containing, on the average, 230 *E. coli* per 100 milliliters during the rainy, and 16 per 100 milliliters during the dry season.

The results obtained at the seven sampling points along the lower reaches of the Jukskei and its continuation in the Crocodile River have been presented graphically in Fig. 8 and 9, for the rainy and dry seasons respectively.

The graph for the rainy season (Fig. 8) shows that the major component group of the bacterial population consists of citrate-utilisers, again indicating that the main contribution by run-off does not consist of faecal organisms. Maximum faecal pollution, as expressed by the number of *E. coli*, exists at Station 9D, with an additional lower peak at Station 22. Faecal streptococci are first reduced, but increase significantly in numbers at Station 20A, another case of "delayed" pollution and possibly an indication that faecal streptococci, under certain circumstances, may survive longer than *E. coli*. After that they fall off towards Station 23 to a figure of 130 per 100 milliliters.

The graph for the dry season (Fig. 9) shows a shift in the distribution of the various components of the bacterial population. Citrate-utilisers have decreased in numbers; at Station 9D they are lower in number than *E. coli*, indicating the comparative severity of the faecal pollution prevailing there. Faecal streptococci reach their maximum concentration at Station 9D, and are then rapidly and progressively reduced, without an additional peak at Station 20A, evidently due to lack of run-off from Diepsloot Farm.

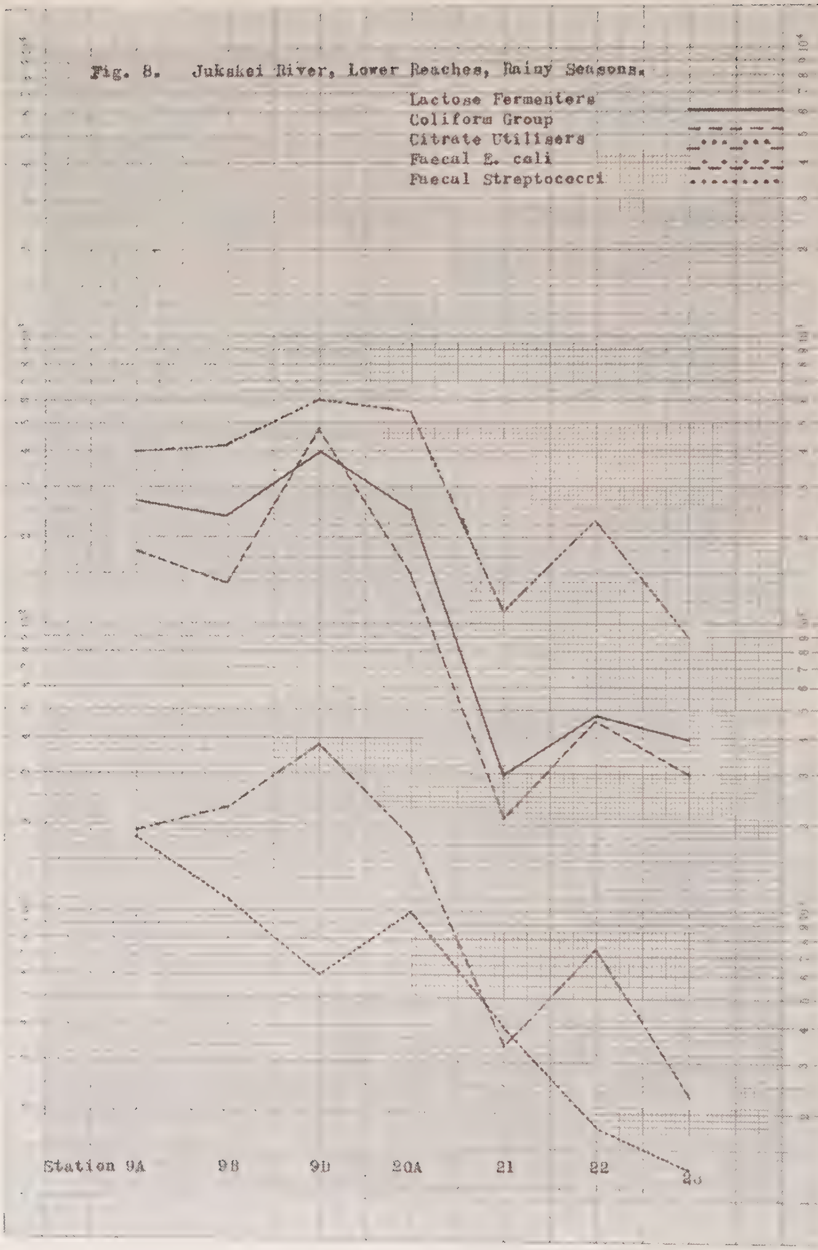
Fig. 8. Jukskei River, Lower Reaches, Rainy Seasons.
Lactose Fermenters
Coliform Group
Citrate Utilisers
Faecal E. coli
Faecal Streptococci
Station 9A
9B
9D
20A
21
22
23

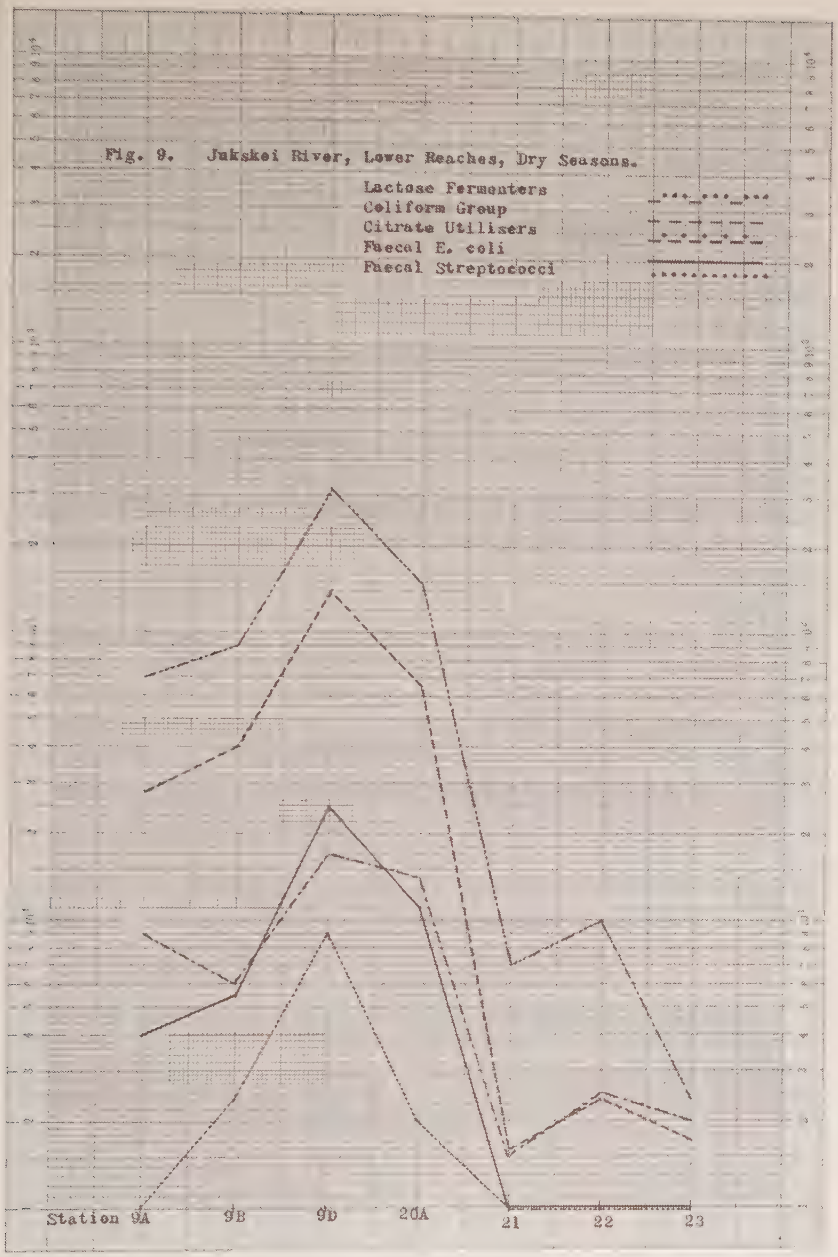
Fig. 9. Jukskei River, Lower Reaches, Dry Seasons.
Lactose Fermenters
Coliform Group
Citrate Utilisers
Faecal E. coli
Faecal Streptococci
Station 9A
9B
9D
20A
21
22
23

VII. FLOW, RAINFALL AND EFFECT OF RUN-OFF

For a limited number of sampling stations, namely, 9B, 20A and 22, flow measurements are available; at Station 9B, rainfall figures have also been recorded. These figures have been plotted against the number of *E. coli* and citrate-utilisers respectively for the corresponding periods of time.

Fig. 14 shows flow, rainfall, *E. coli* and citrate-utilisers for the period from May, 1957 to November, 1958 at Station 9B in the Leeuwkop Prison Farm. It is quite obvious from the graphical presentation that the main contribution by run-off after heavy rains is non-faecal in origin (January to May, 1958). It also becomes evident that after the first rains (September, 1957) there is an appreciable contribution to the faecal component of the bacterial population, which then subsides, to reach a second maximum in February, 1958. Conditions at this sampling point are such that a faecal contribution by run-off can be expected, but it has been found to be of far less significance than the simultaneous contribution of organisms of non-faecal origin.

Fig. 15 shows in graphical presentation flow rates, *E. coli* and citrate-utilisers at Station 20A for the period from May, 1957 to August, 1958. The findings at Station 9B, discussed above, are repeated: there is an increase in *E. coli* at high flow, but again the increase in non-faecal organisms is of far greater magnitude and significance. But it must again be pointed out that a contribution by run-off to the faecal component of the bacterial population is to be expected, as has been explained previously.

Fig. 16 shows flow rates, *E. coli* and citrate-utilisers at Station 22 for the period from August, 1957 to July ,1958. During the period of high flows, December, 1957 to April 1958, the contribution by run-off to the non-faecal components of the bacterial population must have been very large, although varying in degree and magnitude. On the other hand, contribution to faecal pollution has remained practically constant what could also have been expected on the basis of the conditions prevailing at this sampling point.

VIII. THE SELF-PURIFYING POWER OF THE JUKSKEI—CROCODILE SYSTEM

The self-purifying power of the river system has been presented in the following Fig. 17 to 19. The graphs show the stations along the main course of the Jukskei River from its origin in the Bezuidenhout Valley area in Johannesburg (Station 1) to the Hartebeestpoort Dam (Station 23). The distances have been plotted in their correct propor-

tions, the total distance between Station 1 and Station 23 being 51 miles.

Fig. 17 and 18 show *E. coli* and citrate-utilisers during the rainy and dry seasons respectively; Fig. 19 shows the coliform group, *E. coli* and faecal streptococci on the basis of the total average figures presented in Table 1. During the rainy season (Fig. 17) the proportion of non-faecal organisms is at all stations higher than the figures for *E. coli*, again confirming than run-off contributions are mainly non-faecal in origin. During the dry season, *E. coli* is predominant in the upper reaches of the river, with typical peaks at Stations 5 and 9D, where continuous direct faecal pollution occurs throughout the year. On the average (Fig. 19), *E. coli* reaches its maximum at Station 2, with an additional peak at Station 5. The coliform group follows more or less the same pattern as *E. coli*, with the exception that there are additional peaks at Stations 4 and 20A, due probably to additional organic pollution, not necessarily of faecal origin. Faecal streptococci obviously will show a maximum concentration at Station 2, but they exhibit a second strong peak at Station 5, evidently due to the contribution from the so-called composting plant.

IX. DISCUSSION OF RESULTS

In the following discussion of the results of a survey of the Jukskei—Crocodile River System, use has been made of statements and definitions from standard text books, namely, TOPLEY & WILSON's Principles (6), BERGEY's Manual (7, 8), and KLEIN's Aspects of River Pollution (9). These references have been treated collectively in the subsequent sections, and will not be referred to individually.

(*i*) *General Aspects of Water Bacteriology.*

The bacterial flora of natural waters consists of *Pseudomonas*, *Chromobacter* and *Achromobacter* spp., cocci and sarcinae. Discharge of sewage effluents would add *Proteus vulgaris* and *Clostridium sporogenes* to this indigenous population, both of which can be regarded as sewage bacteria proper. But it would also contribute a variety of organisms which are, in the majority, of faecal origin and which comprise the members of the coliform group, especially *Escherichia coli*, enterococci, *Clostridium welchii*, and enteric pathogens of the typhoid—dysentery group.

In a river survey project which deals with a system whose natural bacterial population has been changed by the discharge of sewage effluents, and by other contributions of faecal origin, bacteriological analysis should concern itself with the possible determination of three

primary groups of organisms. The total number of living organisms in the water would give some indication as to the amount of organic matter present in it. The members of the coliform group would indicate the presence of organisms which are at least saprophytic, and which might be parasitic. Faecal *Escherichia coli* Type I would indicate faecal pollution. It is obvious that the more organisms of faecal origin there are, the more likely is the presence of pathogenic species among them. For river quality determinations, therefore, not the indigenous bacterial flora, but the adventitious flora is of prime importance.

Kolkwitz & Marsson originally devised a system of saprobia in an effort to classify river water quality according to the fauna and flora encountered under certain conditions. Their original system has been revised by Liebmann (10). Bacteria do not enter into the classification of the saprobic system, except in the form of total counts. There is no attempt at a differentiation into specific groups. Bacteria serve as indicators of pollution generally under polysaprobic conditions, when the total count reaches 1,000,000 or more organisms per milliliter. Both Liebmann and Strell (11) attach some importance to organisms with distinct morphological characteristics like *Spirillum* spp. or like sulphur and iron bacteria which may serve as indicators of specific biochemical activities. Organisms like *Sphaerotilus*, *Beggiatoa*, *Leptomitus* and *Zoogloea* also play some part in the classification, but they are of no practical importance under South African conditions, since they do not occur in the massive accumulations of "sewage fungi" seen in Europe.

With progressive self-purification in a river system, bacterial numbers are reduced; the total count drops to 100,000 organisms per milliliter under α- and β-mesosaprobic conditions. A water with a total count of 100 or less organisms per milliliter is classified as oligosaprobic.

On the basis of the total count alone, it has not been possible to classify individual sampling stations into their respective zones, or to define the degree of pollution. But an attempt has been made to assess, from a purely bacteriological point of view, the significance of the various components of the bacterial population in their relation to faecal pollution and self-purification.

(*ii*) *The Methods Used for Analysis.*

Bacterial counts on nutrient agar give information as to the number of living micro-organisms of all sorts in the sample, strictly relative to the exact conditions of the test. The more bacteria present, the greater the amount of organic matter which supplies their nutritional requirements, and the greater the likelihood that the water is con-

taminated with parasitic and potentially pathogenic organisms as well as with saprophytic ones. The temperature of incubation is an important factor. Whereas at 20°C. mainly the natural and harmless bacteria of water develop, organisms of soil, sewage or excretal origin will thrive at 37°C.

In clean water, about ten times as many organisms will grow at 20°C. as at 37°C. In a polluted water, the ratio is very often less. But it may vary within wide limits, and quite independently of the extent of faecal pollution. It has not been found that the total count at 37°C. as such constitutes a valid indication of faecal pollution. There may be wide seasonal fluctuations in the total count, but these fluctuations are not reflected in the number of organisms of faecal origin unless there are quite specific reasons for their presence. A high total count, therefore, does by no means indicate severe pollution due to sewage or faecal matter.

It has been regarded as possible to subdivide the coliform group of organisms into three sub-groups on the basis of the reactions obtained in differential liquid media. It is realised, however, that this method has certain shortcomings, since the media employed are not quite as specific as they have been assumed to be for the purpose of the sub-division mentioned. A distinction has been made between organisms of unmistakably faecal origin, *Escherichia coli*, organisms of possibly faecal origin, the coliform group, and organisms non-faecal in origin, *Aerobacter aerogenes*. Detailed topographical studies of the drainage areas of individual sampling stations were of great assistance in the interpretation of the actual laboratory determinations, and seemed to provide a certain degree of justification for the simplified method of classification adopted.

Organisms which are capable of growing in lactose broth at 37°C. with the production of gas have been classified generally as lactose-fermenters. This group may consist largely of coliform organisms, but it also comprises the so-called "slow lactose-fermenters", *Clostridium* spp., various aerobic spore-formers, paracolon bacteria, and others. Moreover, positive reactions may result from synergistic action by two different species neither of which can alone produce acid and gas from lactose. Most Probable Numbers for lactose-fermenters are, with very few exceptions, higher than the numbers for the coliform group which grows under optimum conditions in brilliant green bile lactose broth.

Brilliant green bile lactose broth "measures" only the coliforms, whereas lactose broth "counts" these same coliforms plus an assortment of other bacteria of negligible or unknown epidemiological significance. Apparently anomalous results sometimes appear, and have been recorded, where some stations are shown as having con-

sistently on the average more coliform organisms than lactose-fermenters. These apparent anomalies should rather be ascribed to overgrowth of the lactose-fermenters by other organisms than to normal sampling errors which have been compensated for the treatment of the individual results.

The number of organisms belonging to the coliform group is obviously a more reliable index of the possibility of faecal pollution than the total count. But determinations of the coliform group as such are still not sufficient as a final criterion of faecal pollution. *Aerobacter aerogenes* is normally found in water and soil, on grains and plants, and only to a varying degree and infrequently as an inhabitant of the intestinal canal of man and other warm-blooded vertebrates. It is widely distributed in nature and therefore unspecific in its habits.

Differentiation between the coliform group as such and the typical intestinal parasite *Escherichia coli* Type I therefore seems to be essential. *E. coli* is usually of faecal origin, while other types of coliforms are usually derived from other sources. *E. coli* is a normal inhabitant of the human intestinal tract and of the intestines of warm-blooded animals. The MacConkey test at 44.5°C. is regarded as practically diagnostic for *E. coli* Type I. It seems logical, therefore, to use *E. coli* as the most sensitive index of faecal pollution.

In warm climates, a number of irregular and intermediate types and some strains of *Aerobacter aerogenes* are capable of fermenting lactose at 44.5°C. In sewage-contaminated waters, faecal *E. coli* would be expected to predominate amongst the organisms producing a positive reaction, and such "false positives" as might occur would have little or no sanitary significance. In relatively pure waters, however, there may be a sufficient number of non-faecal coliforms capable of fermenting lactose at 44.5°C., to give a somewhat misleading impression as to the bacteriological condition of the river. In such cases, detailed knowledge of the topography of the drainage area of the sampling station, and of the possible sources of pollution is essential. This reservation applies in particular to the Klein Jukskei River.

In parallel with *E. coli*, faecal streptococci (enterococci) have been determined regularly, using buffered azide glucose glycerol (BAGG) broth which, according to Hajna (12), produces almost definite evidence of the presence of enterococci, the criteria being growth and production of acid after incubation for 48 hours at 37°C. Usually the results for *E. coli* and enterococci are in good agreement; the ratio between the two groups is fairly constant under closely similar conditions. It appears that this ratio between *E. coli* and faecal streptococci (E: S ratio) is of some significance for the assessment and evaluation of faecal pollution (13). The interpretation of the results

is to some extent affected by the rate at which the two organisms die out after gaining access to water, but it appears from the results reported here that enterococci survive longer than *E. coli* even though they may be reduced initially at a higher rate. Faecal streptococci could be regarded as indicators of what has been termed "delayed" pollution under specific conditions, where *E. coli* is present in small numbers only or totally absent, while enterococci in appreciable numbers are still in existence. It has also been found that at sampling points which are subject to direct faecal pollution by cattle, the ratio between *E. coli* and enterococci, which is usually above 1, falls below unity, indicating that there are more enterococci than *E. coli*. Since *Streptococcus faecalis* and its variants as well as *Str. bovis* are of faecal origin, further differentiation has not been considered necessary.

To obtain additional information on the composition of the bacterial population, in particular with respect to components of possibly non-faecal origin, Koser's citrate medium (14) has been used as a routine medium for M.P.N. determinations in parallel with the other liquid media for the coliform group. Theoretically the number of citrate utilisers and that for *E. coli* should add up to the number of organisms belonging to the coliform group, considering that Koser's citrate medium is of similar specificity for *Aerobacter aerogenes* as MacConkey broth for *E. coli* Type I. In fact this simple addition does not work out; MacConkey broth may show the presence of coliforms of the intermediate group, and citrate definitely shows the presence of certain pigmentproducing organisms, probably *Pseudomonas* and *Chromobacter* spp., both of which are, however, not of faecal origin, and, in the author's opinion, do not detract from the value of the determination.

Superficially, it would appear that a risk exists of introducing with the inoculum sufficient organic matter to support visible growth of organisms which are not, in fact, capable of using citrates as their sole source of carbon. In practice, this apparent disadvantage may not have arisen.

Again, Koser's citrate medium is not exclusively specific for non-faecal coliforms. Some non-faecal forms of the coliform group, e.g. *E. coli* Type II and the irregular strains, are incapable of using citrate, whereas a large number of bacteria which are not coliforms at all, do utilise citrates. This latter group includes *Pseudomonas* and *Chromobacter* spp., genera which are usually abundantly represented in soil, vegetation and natural waters, and which may therefore be expected to have a substantial effect on the results where M.P.N. procedures are employed.

This point is illustrated in the figures for the Klein Jukskei River, where citrate-utilisers were about 5 to 10 times as numerous as the

coliforms, suggesting that the majority of the organisms measured were not coliforms at all, but probably *Pseudomonas* and *Chromobacter* spp. Probably the proportion of non-coliform citrate-utilisers is very much smaller in the "sewage streams", but there is at present no means of assessing how much smaller, or what allowances should be made for them in considering the results.

The figures appearing in this study suggest that the organisms measured in Koser's citrate are a heterogeneous and variable assembly, whose epidemiological importance can not readily be gauged. But on the other hand, it seems justified to assume that they are, as a whole, non-faecal in origin, and that their determination can be utilised in the differentiation between organisms of faecal and of non-faecal origin.

(iii) Percentage Distribution of Faecal and Non-Faecal Components of the Bacterial Population.

A method has been developed to interpret numerical results of bacteriological analysis on the basis of the percentage distribution of three significant groups of organisms which have been determined quantitatively by the use of relatively specific liquid nutrient media.

The total count has been disregarded for this purpose, because, in the author's opinion, very little importance and significance attaches to it as regards the objective of this study which were the assessment of the degree of faecal pollution and the definition of its sources. Lactose fermenters, as measured in lactose broth, and the coliform group, as counted by the use of brilliant green bile lactose broth, have also been disregarded since it was felt that their inclusion in a sum total of the organisms determined would result in too much duplication and overlapping.

Plotting the percentage distribution of the three remaining groups, namely, enterococci, citrate utilisers and *E. coli*, on the other hand, should provide a very clear picture as to the relative significance of the numerical results, and should make it possible to draw definite conclusions as to the actual degree of pollution at any sampling point and any given time, and as to the relative significance and potentiality of sources of pollution along the course of the river.

The percentage distribution of these three groups of organisms, which should comprise all faecal components and the non-faecal organisms falling into the coliform group, is presented in the following four block diagrams, Fig. 10 to 13. The figures present the four sections of the river system and show next to each other percentage figures for the rainy and dry seasons respectively.

The first striking feature of this presentation is the fact that during the dry season the proportion of organisms of faecal origin is higher


%
100
90
80
70
60
50
40
30
20
10
0
1 2 3 4 5 6 8
R D R D R D R D R D R D R D
Upper Jukskei
Enterococci
Citrate Utilisers
E. col.

Fig. 10

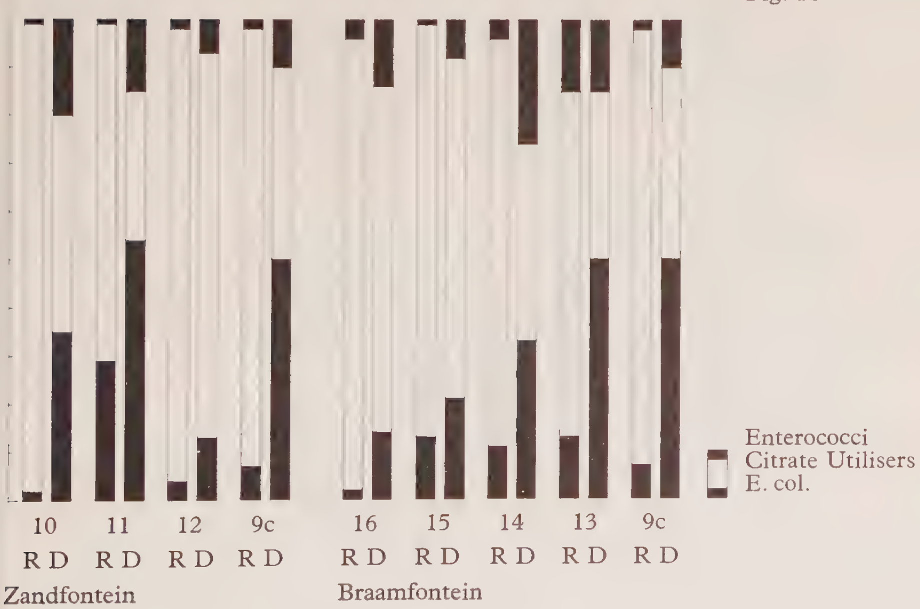
10 11 12 9c 16 15 14 13 9c
R D R D R D R D R D R D R D R D R D
Zandfontein
Braamfontein
Enterococci
Citrate Utilisers
E. col.

Fig. 11

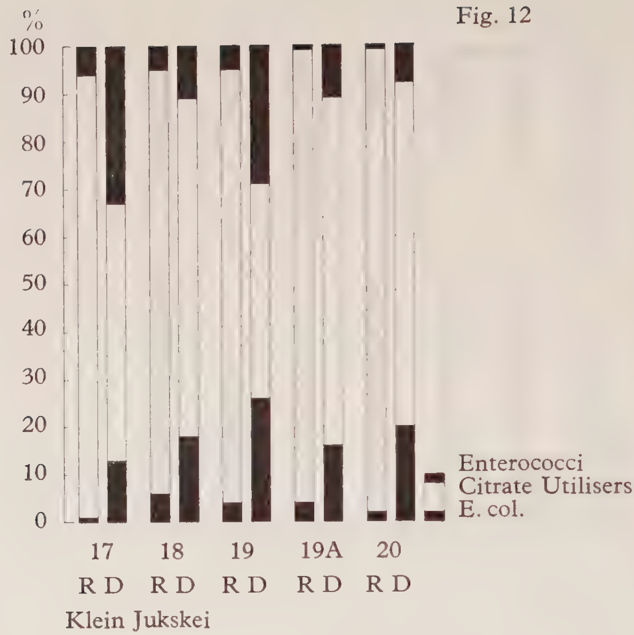
%
100
90
80
70
60
50
40
30
20
10
0
17
18
19
19A
20
R D R D R D R D R D
Klein Jukskei
Enterococci
Citrate Utilisers
E. col.

Fig. 12

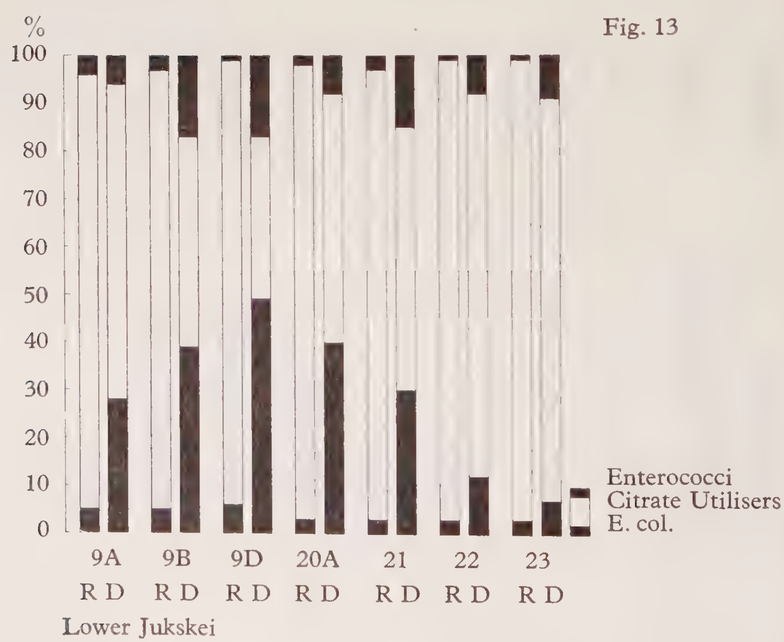
%
100
90
80
70
60
50
40
30
20
10
0
9A
9B
9D
20A
21
22
23
R D R D R D R D R D R D R D
Lower Jukskei
Enterococci
Citrate Utilisers
E. col.

Fig. 13

than during the rainy season. At the same time, it becomes apparent that the proportion of citrate-utilisers is higher during the rainy season than it is during the dry season. It is hardly possible to supply more convincing proof for the fact that the contribution by run-off to the bacterial population is normally non-faecal in origin, unless quite specific conditions prevail in the drainage area.

During the dry season, on the upper reaches of the Jukskei River, the faecal components of the bacterial population are highest in numbers at Station 1, and lowest at Station 4, where a certain amount of self-purification in the absence of possible sources of additional pollution has taken place. Pollution, as expressed by the proportion of faecal to non-faecal organisms, reaches a high degree at Station 5, due to severe direct faecal pollution.

In the sewage streams, pollution appears to be more severe in the Braamfontein than in the Zandfontein stream. Peak figures are reached at Station 11 on the Zandfontein stream, both during the rainy and the dry season, and obviously due to the discharge of sewage effluents. On the Braamfontein stream, however, conditions are unsatisfactory at Stations 15, 14 and 13, during the rainy as well as during the dry season, and due to the variety of factors discussed in an earlier section.

Along the Klein Jukskei, conditions are, on the whole, fairly satisfactory. The features brought out by the block diagram have been mentioned in the discussion of the individual sampling points.

The graphic presentation of the lower part of the Jukskei—Crocodile River System seems to indicate that on the whole self-purification operates fairly efficiently, at least for the time being and for the period under investigation. Again, statements referring to Stations 9D and 20A are very well illustrated by the graph.

(iv) Seasonal Variations, Run-Off and Self-Purification

The numbers of bacteria in river waters are naturally very variable and depend on a wide variety of factors. Access of soil and organic matter and increases in temperature may be responsible for increases in bacterial numbers. Both these factors are of particular importance under South African conditions where in many parts of the country the year is clearly subdivided into a rainy summer and a dry winter season. Soil bacteria will always and under all circumstances increase in number after heavy rain and flooding; undoubtedly the results of this survey support this assumption.

According to investigations carried out by the Water Pollution Research Laboratory at Stevenage (15), the number of bacteria increased considerably during wet weather; bacterial counts were two to four times as great below the outfall of a sewage disposal

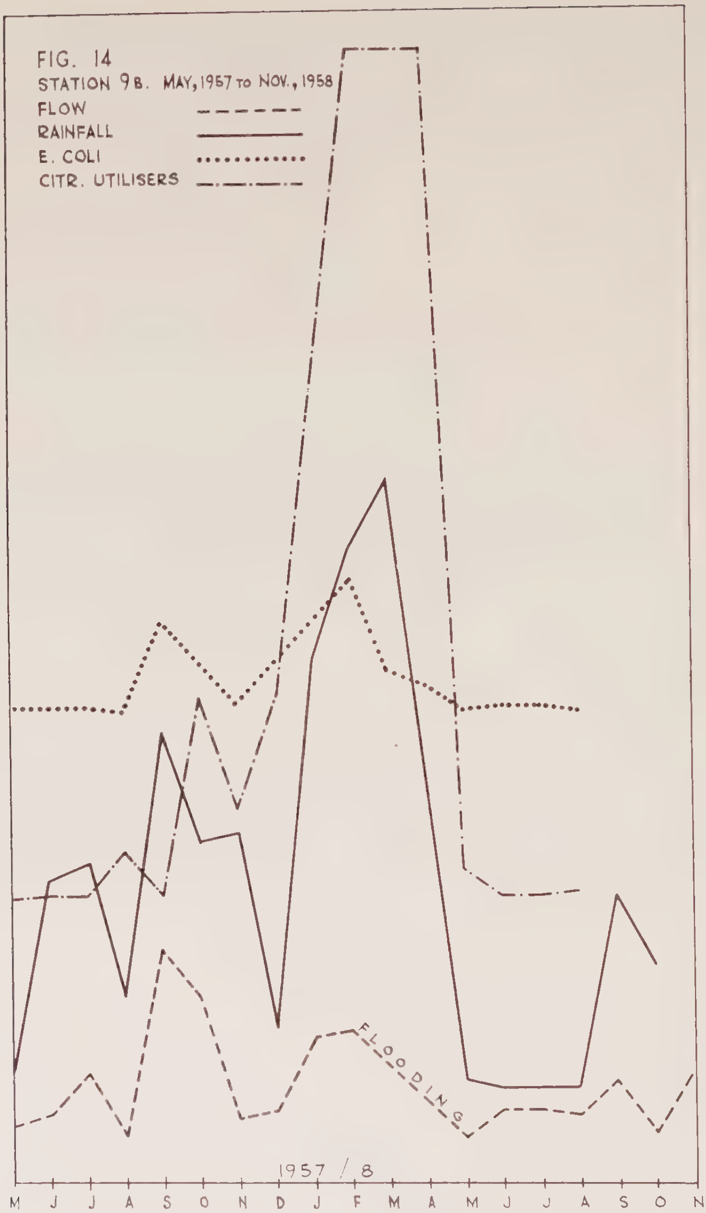
FIG. 14
STATION 9B. MAY, 1957 TO NOV., 1958
FLOW
RAINFALL
E. COLI
CITR. UTILISERS
FLOODING
1957 / 8
M J J A S O N D J F M A M J J A S O N

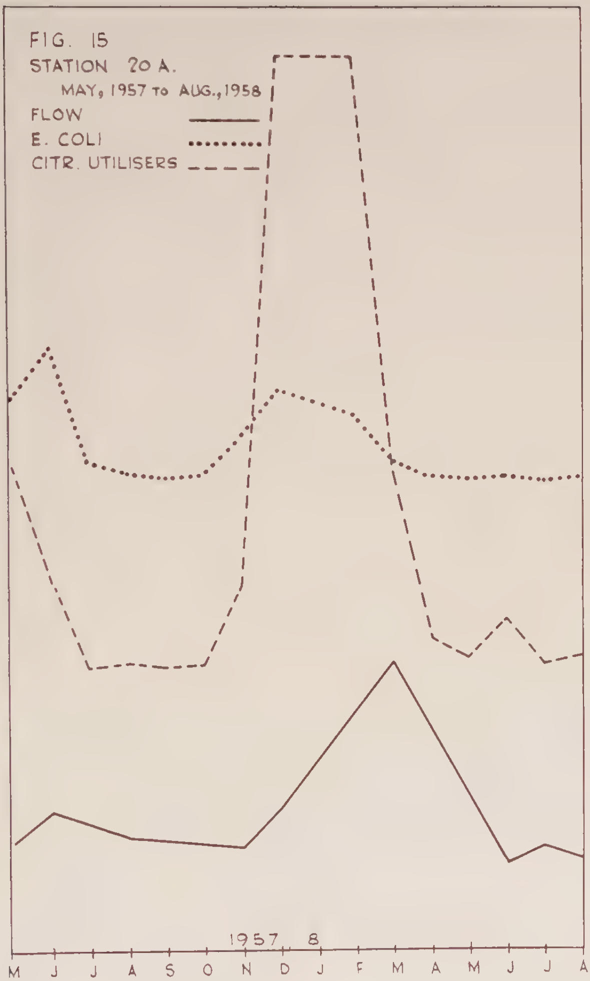
FIG. 15
STATION 20 A.
MAY, 1957 TO AUG., 1958
FLOW
E. COLI
CITR. UTILISERS
1957 8
M J J A S O N D J F M A M J J A

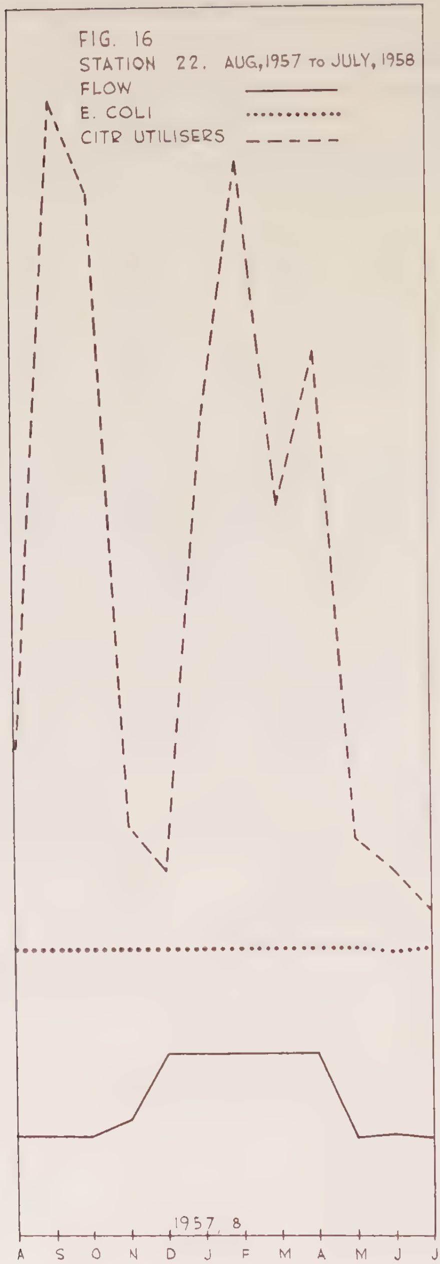
FIG. 16
STATION 22. AUG, 1957 TO JULY, 1958
FLOW
E. COLI
CITR UTILISERS
1957, 8
A S O N D J F M A M J J

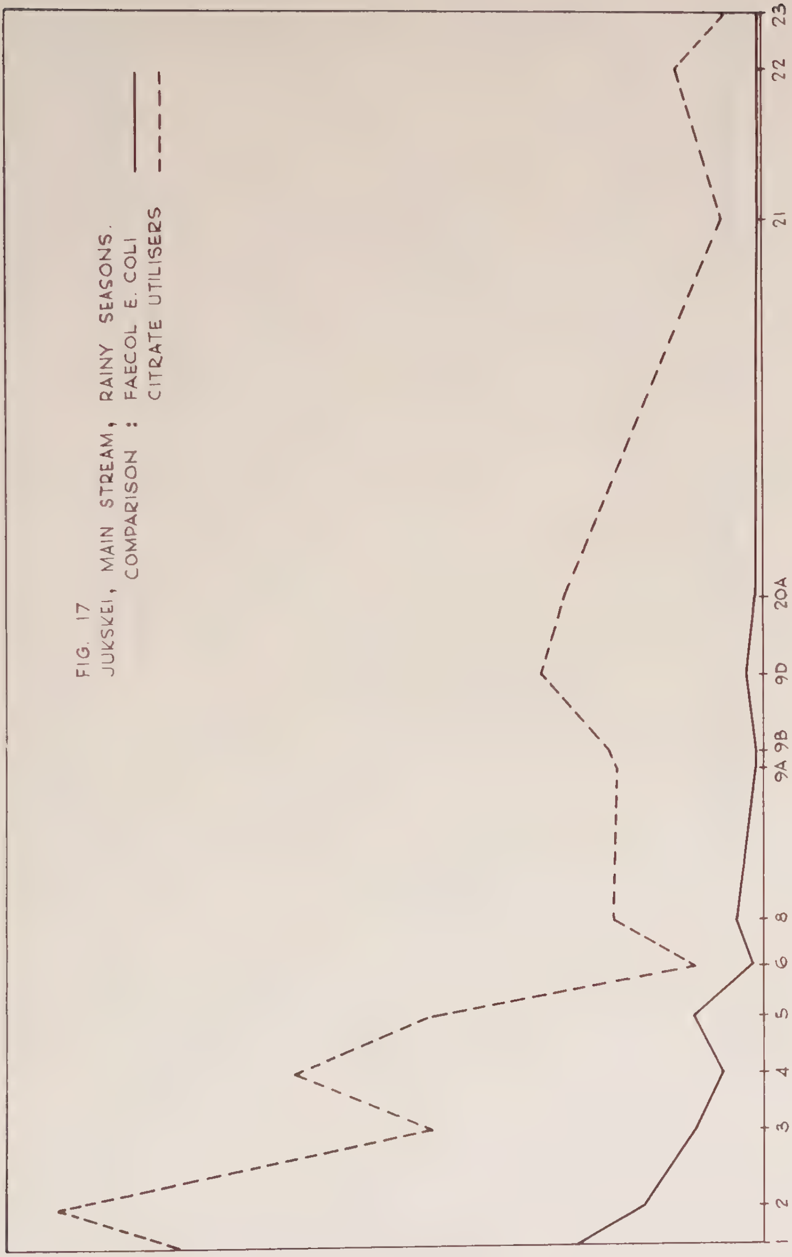

FIG. 17
JUKSKEI, MAIN STREAM, RAINY SEASONS.
COMPARISON : FAECOL E. COLI
CITRATE UTILISERS

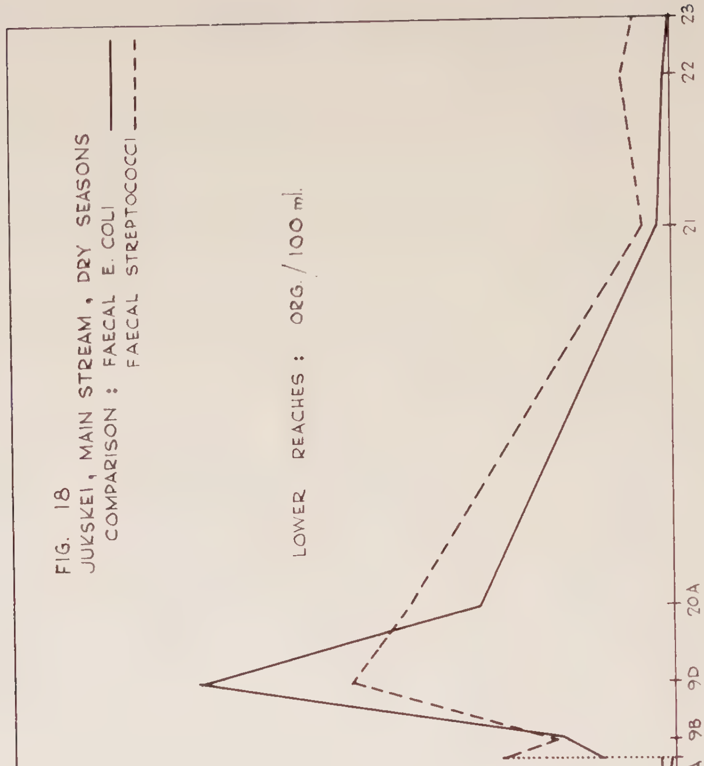

FIG. 18
JUKSKEI, MAIN STREAM, DRY SEASONS
COMPARISON : FAECAL E. COLI
FAECAL STREPTOCOCCI
LOWER REACHES : ORG./100 ml.
UPPER REACHES: ORG./ml
1
2
3
4
5
6
8
9A
9B
9D
20A
21
22
23

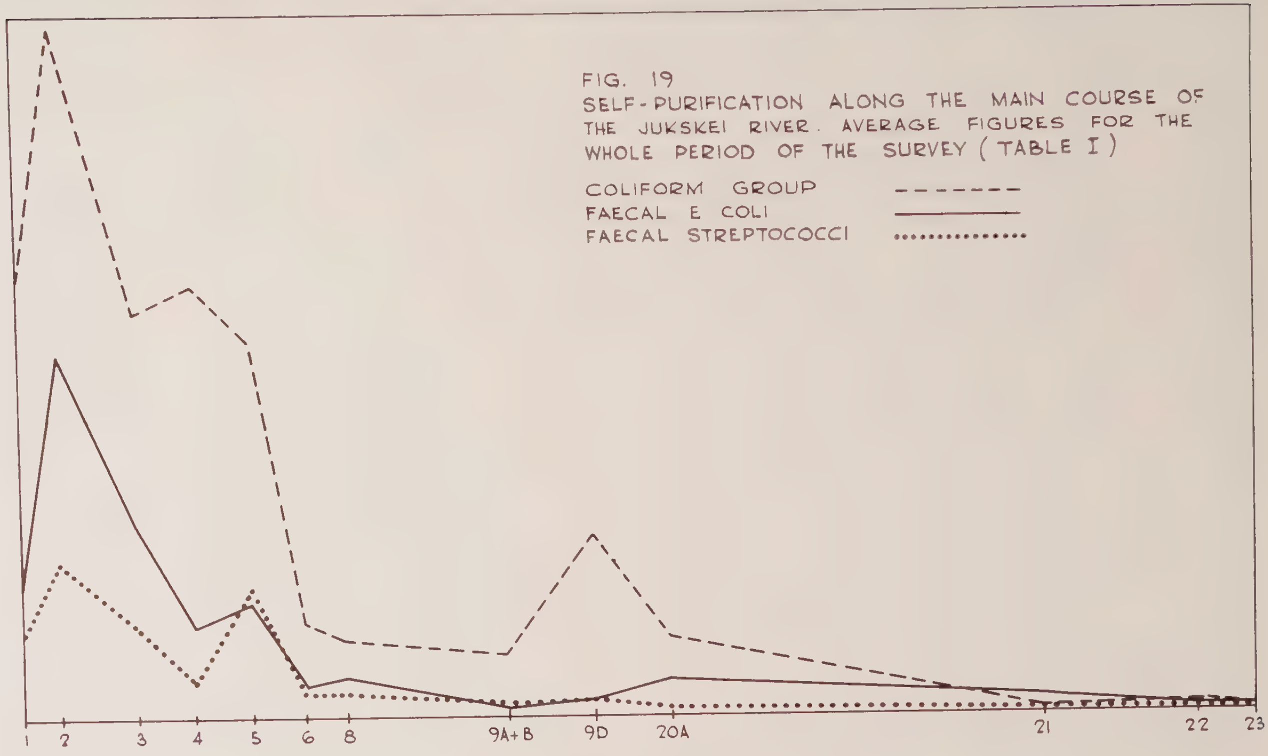
FIG. 19
SELF-PURIFICATION ALONG THE MAIN COURSE OF THE JUKSKEI RIVER. AVERAGE FIGURES FOR THE WHOLE PERIOD OF THE SURVEY (TABLE I)
COLIFORM GROUP
FAECAL E COLI
FAECAL STREPTOCOCCI
1
2
3
4
5
6
8
9A+B
9D
20A
21
22
23

works in wet weather than in dry weather. It was suggested that one of the factors responsible for this increase was the operation of storm overflows and the discharge of storm water sewage during heavy rains.

Usually, particularly during the rainy season, citrate-utilisers are predominant over the other groups. The contribution by run-off to the bacterial population of the river is usually reflected in increases in the number of citrate-utilisers and in the total count, but not in the number of faecal or possibly faecal organisms, unless specific conditions prevail in the drainage area of the sampling station.

In an unpolluted stream there is usually a sharp drop in the bacterial population during the dry season, when there is no contribution by run-off, and when bacteriological analysis can be relied on to show only organisms which are indigenous to the river and which constitute its normal population. In polluted streams this statement holds true to a certain degree and with certain modifications. Disregarding the total number of organisms of all sorts, which appears justifiable on the assumption that the total count is of little value and significance in the determination of the extent and degree of faecal pollution, and utilising the percentage distribution of the three groups of significant organisms which have been determined quantitatively, it appears that during the dry season there is an increase in the relative number of faecal organisms, corresponding to a decrease in the number of non-faecal or soil organisms.

At sampling points subject to direct faecal pollution due to the discharge of sewage effluents, even during the rainy season the proportion of organisms of faecal origin is higher than the proportion of citrate-utilisers, indicating that the effects of sewage effluent, though diluted by rain and run-off, are much stronger than the influence of the run-off as such.

In general, seasonal variations at such sampling points are not particularly marked.

On the whole, faecal pollution to any considerable degree in a previously unpolluted section of a river system only appears with increasing human activity, and with the increasing probability of incidental faecal pollution.

A generalisation of these findings, however, is impossible for obvious reasons. The final effect of self-purification and the effect of drainage and run-off depend entirely on the conditions prevailing in the respective drainage areas, and on the quality of the run-off which reaches the river from various sources along its course.

When collecting samples, it is of the utmost importance for the bacteriologist to make a thorough topographical survey of the drainage area of his sampling station, so as to ascertain the extent and the type

of pollution to which the sampling point is subject. Detailed attention has been given to this factor, and an extensive study of the topographical features in the vicinity of sampling stations has been carried out. The information gained from these locality inspections is of the greatest value in the interpretation of the results and for the conclusions drawn from them.

Self-purification by bacterial action is supposed to be effected mainly by aerobic heterotrophic organisms. According to our experience, self-purification must largely take place in the free water zone. Factors determining the efficiency of purification by the actions of micro-organisms are their ability to feed on living or dead tissues, their capacity to utilise organic and inorganic materials in solution, and their power to make use of free or combined oxygen. Rapid decreases in bacterial populations can not be accounted for by dilution only; under South African conditions, the factor of dilution probably plays a minor role only, especially during the dry season. A number of factors must be involved in the reduction of bacterial numbers, amongst them natural death in the absence of nutrient material, competition between various groups of organisms, sedimentation of the suspended matter to which the organisms have become attached, predatory activity of protozoa and other bacterial feeders, and the presence of bactericidal substances and bacteriophage.

On the whole, self-purification in the Jukskei—Crocodile System appears to be progressive and satisfactory. In the upper reaches of the Jukskei River, up to the confluence with the little stream from the Modderfontein lagoons, and in the sewage streams, self-purification is capable of coping with the initial detrimental effects of the discharge of sewage effluents more or less completely. Self-purification is more marked in the upper reaches of the Jukskei River and in the Zandfontein stream than in the Braamfontein River. In the lower reaches of the Jukskei—Crocodile System, the power of self-purification seems to be somewhat impaired, due to discharges of industrial effluents, although their effects may not be directly reflected in bacterial numbers or in the composition of the bacterial population.

(*v*) *Value of Methods and Validity of Interpretation.*

The evidence obtained by bacteriological analysis is of necessity circumstantial. Interpretation of results is often open to doubt. But results and interpretations should show the normal range of variation, and should allow conclusions as to the bacteriological character of the water.

It can be stated that

(a) The use of the methods of bacteriological analysis described,

(b) The interpretation of the numerical results in the light of all other data vailable,
(c) Utilisation of the percentage distribution of certain components of the bacterial population, and
(d) Any other relevant information collected during the actual field work form together a body of valuable and valid data. On the basis of this accumulation of experimental data it should be possible to form conclusions as to the extent of existing faecal pollution, the various sources of this pollution, and the efficiency of self-purification exhibited by the river system in dealing with this pollution.

Apart from the fact that the combination of methods and techniques which have been described and discussed, seem to offer a valuable tool for the investigation and quality assessment of prospective sources of raw water supplies from the purely bacteriological point of view, they should, in conjunction with biological, algological and chemical studies provide a clear picture of conditions in any river system at any given time and point. The bacteriological studies reported here have contributed substantially to a collection of data for future reference, and may prove of value to workers at a later stage.

X. CONCLUSIONS

The final conclusions which have been drawn from the foregoing description and discussion are that
(a) although fairly severe pollution undoubtedly exists in certain parts of the Jukskei—Crocodile System, the ensuing deterioration in water quality has not yet reached a stage which could be termed alarming, and it does not appear that such a stage will be reached in the near future. To attempt a subdivision of the river system into specific saprobic zones, or to lay down a fixed standard of water quality to be maintained or to be enforced, seems to be too dogmatic to be appropriate under the circumstances, although a Tentative Stream Standard should be proposed on the basis of this survey.
(b) The discharge of effluents from chemical factories seems to have little effect on the bacterial population of the river. There may be a change in the composition of the bacterial population, but there is no change in magnitude. Methods could easily be designed to determine the relative numbers of organisms favoured by circumstances created by any particular effluent.
(c) Conditions in the upper reaches of the Jukskei River and in the Zandfontein and Braamfontein streams are obviously due to the

discharge of sewage effluents and, in part, to additional pollution of faecal origin which has been described in detail. Incidental direct faecal pollution plays a certain part in the over-all picture of pollution. But it has not been found that run-off from African townships and from native areas generally contributes to the faecal pollution of the river.

(d) It appears that with an increase in human population and activities along the course of the river conditions in the system may deteriorate at a more rapid rate than at present. Slight progressive deterioration of the lower reaches of the Jukskei—Crocodile System has been observed during the period under investigation, and there are reasons to assume that this decline in quality is not temporary.

(e) An expected further increase in the population density and in human activities would make it advisable to keep a watchful eye on the Jukskei—Crocodile System, and particularly on the Hartebeestpoort Dam, especially in view of the possibility that some date in the not too distant future the water reserves provided by the system may have to be utilised for purposes other than recreational and agricultural.

(f) At the moment the waters of the Jukskei—Crocodile System should be perfectly suitable for agricultural purposes. But it must be said that at some of the camping sites and picnic spots along the river the recreational quality of the stream appears to be somewhat doubtful from a purely aesthetic point of view, not so much from the public health point of view, unless the river is infested with bilharzia-carrying snails which infestation does, however, not coincide with sewage pollution.

XI. SUMMARY

A combination of routine methods of bacteriological analysis has been utilised to investigate conditions in a river system which in part is subject to the effects of the discharge of appreciable quantities of sewage effluents which, during the dry season, may constitute the major part of the total flow. Other parts of the river system are free from gross pollution, and results obtained from these sections served as a basis for comparison. The river system is capable of coping with most of the detrimental effects of direct faecal pollution in varying form. But under no circumstances do these findings imply that the river system is capable of dealing with unrestricted quantities of sewage effluents for an unlimited period of time. Industrial pollution of varying character has been found to have little, if any, effect on

bacterial numbers. The effect these effluents may have on the composition of the bacterial population as a whole has not been investigated, but this influence would be of local significance only. The methods used and the interpretations applied to the results seem to constitute a valuable instrument in the detailed study and assessment of bacteriological quality of the waters in a natural river system which is subject to severe pollution from sewage and industrial effluents of varying character.

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Observations on Furcellaria fastigiata (L.) Lam. forma aegagropila Reinke in Danish waters together with a note on other unattached algal forms

by

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INTRODUCTION

ROSENVINGE (1917) described *Furcellaria fastigiata* as one of the commonest and most widely distributed seaweeds in Danish Waters. He pointed out that *Zostera* was the major producer of organic matter in the benthos, but placed *F. fastigiata* fourth, and next only to *Fucus* and *Laminaria*, amongst the algae which play a principal part in the composition of the vegetation. In the Baltic *(sensu stricta)* the species, although reduced in size, is a very conspicuous member of the marine flora. In the attached state it may form broad belts and cover up to 25% of the submerged rock surface within its zone (WAERN 1952; DU RIETZ 1932), or it may occur as the dominant alga in association with *Rhodomela confervoides* (HUDS.) SILVA, *Phyllophora brodiaei* (TURN.) J. AG., *Polysiphonia* spp. or *Mytilus edulis* (L.,) (SVEDELIUS 1901; DU RIETZ 1925; LEVRING 1940). Around the coasts of the Baltic Islands, Öland and Gotland, *F. fastigiata* is abundant and has the local name of „Krakel" which, together with *Rhodomela confervoides* ('Ylle'), is used as a fertilizer (WAERN 1952).

The loose unattached form of the species, forma *aegagropila* REINKE, also noted by ROSENVINGE, is sufficiently abundant locally in Danish waters to form the basis of a source of agar production. This weed has been harvested in increasing quantities since 1943 and today supports a flourishing industry, using ebout 18,000 tons of *F. fastigiata* yearly.** It was also at one time thought possible that reducing sugars, in which some red algae are comparatively rich (ROSS 1955), might be extracted from the plant on a commercial scale. LUND & BJERRE-PETERSEN (1952) have given a short account of the harvesting and utilization of the species for agar. Their account,

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* Most of the observational work in this paper was carried out in the Department of Botany, Aberystwith.

** Personal communications with HERR FUGLEDE of Skibet.

mark in 1955, and more recent information from the processing companies, indicate that the bulk of the weed has been and still is being collected from the southern part of Aalborg Bay near the western shores of the central Kattegat (Fig. 1 Km).

The hydrography of the Danish waters has been dealt with by Rosenvinge (1909) and his geographical division of the region is adopted here (Fig. 1).

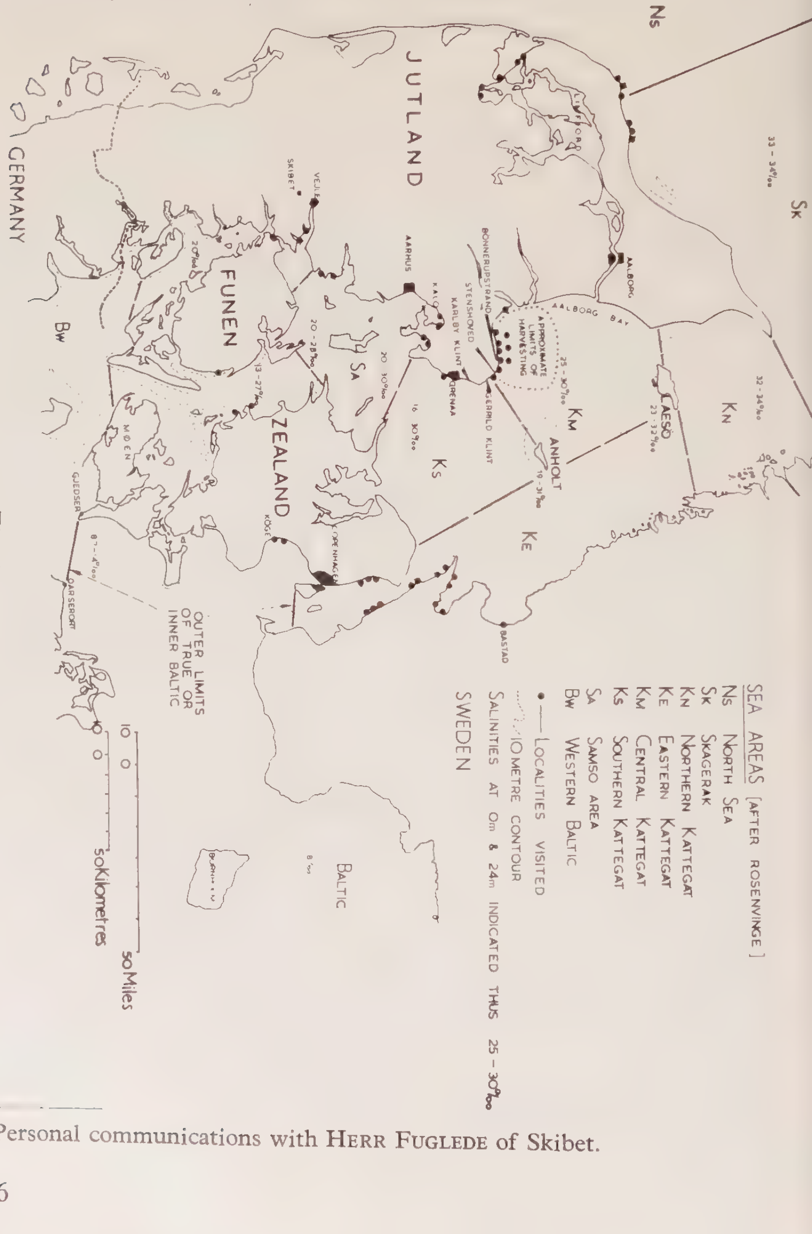

Fig. 1.
Map of the Danish Waters (after Rosenvinge 1909)

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* Personal communications with Herr Fuglede of Skibet.

The area where the forma *aegagropila* is most abundant lies in the extensive shallow region which stretches from the mouth of the Limfjord in the north to Grenaa in the south and is bounded on the east by the islands Laesø and Anholt (Fig. 1). These islands, together with their surrounding shallows, form a bar or shelf separating the area from the deeper channels or belts, through which strong currents flow. The water in the northern part of this area and along the coast of Jutland is relatively saline (24‰—33‰ ROSENVINGE 1909) due to influx from the northern Kattegat through the Laesø channel, but there is little or no thermal stratification. However, there is a considerable seasonal range of temperature in this shallow region (1.5° C—17° C, ROSENVINGE 1909) and ice formation during severe winters may temporarily interfere with the collection of the weed. Within the 10 metre contour which lies some 10—20 kilometres from the shoreline the sea bottom is almost entirely formed of muddy sand, except for some few stones here and there, mostly to the seaward of boulder reefs, as at Stenshoved, Gerrild and Karlby Klint (Fig. 1). In 1955 observations close inshore showed that the surface layer of clean yellow sand was 2″—3″ thick and below this gave way to black muddy sand smelling of hydrogen sulphide and no doubt rich in bacteria and decaying organic matter. Conditions similar to these are common in many of the shallow Danish bays.

The above described region is part of a much larger one with a bottom fauna, dominated by *Venus* and *Echinocardium* (PETERSEN 1911; CLEMENTS & SHELFORD 1949), typical of level sandy bottoms and of waters of a relatively eutrophic nature.

FURCELLARIA FASTIGIATA AND ITS ECOTYPE FORMA AEGAGROPILA

In the attached state, *F. fastigiata* shows a certain degree of variation in size and thallus diameter. This variation is seen as a result of position on the shore and of exposure conditions (AUSTIN unpublished data), and is seen both on the shores of Britain and also in regions such as the Arctic Sea and the inner Baltic, where rigorous conditions bring about dwarfing. So small and stunted are some plants that they have been given the status of forms, viz. forma *minor* AG. and forma *tenuior* ARESCH. However, these forms, as far as can be judged from the literature, appear to resemble the typical attached form in all important respects, other than extreme reduction in size and consequent sterility. The loose lying forma *aegagropila*, on the other hand, differs from the attached forms not only in regard to thallus diameter and sterility but also in regard to habit, to the absence of normal haptera, and to the presence of adventitious proliferated branches of a special

type (see below). All these features are a result of the habitat in which the plants live.

The type specimen, named by LINNAEUS, *Fucus fastigiatus*, was collected from the inner Baltic (see DREW 1958) and, though resembling the above mentioned dwarf forms and the unattached form in its small thallus thickness, is in all other respects typical of the more common attached variety. Therefore, it is reasonable to accord to the forma *aegagropila* the status of an ecotype of the species. Indeed, it would appear that some early authors, for example ÖDER (1768), believed that the unattached form, which he called *Fucus fastigiatus* was a separate species from the normal attached plant, which he called *Fucus furcellatus*.

ROSENVINGE (1917) dredged at three localities in Aalborg Bay along the north shore of Djursland and recorded the loose form of *Furcellaria* at each locality. He observed that some of the plants were like normal ones and that others were branched and formed globular bushes corresponding to those mentioned by REINKE (1889) and SVEDELIUS (1901) as forma *aegagropila*. In 1955 an abundance of this unattached form was observed at a number of points throughout the same area. A great deal of dry cast-up specimens of the forma *aegagropila*, covered with shells of *Spirorbis borealis* DAUDIN, were seen among the dune plants and on the roadsides as well as on the beach. Both the freshly cast-up weed and the abundant plants that were collected by wading and swimming in the extensive shallow water between Bønnerupstrand and Stenshoved Klint (Fig. 1) also consisted entirely of the forma *aegagropila*. Further east it was found in large quantities cast up between Gerrild Klint and Karlby Klint (Fig. 1), but a number of specimens of the normal attached *F. fastigiata* were seen here and later found growing on stones in two metres of water some 60—100 metres offshore.

Further observations were made during harvesting trips on board M. F. V. 'Two' (Fig. 2) during July and August 1955. Dredging was carried out between 2 and 6 kms. due north of Bønnerupstrand with an ordinary otter trawl, which, on most occasions, was brought up after short hauls of 10—15 minutes full of huge masses of crisp glistening bunches of *Furcellaria fastigiata* forma *aegagropila* (Fig. 2), almost entirely free from admixture with other species (cf. *Phyllophora* in the Black Sea, SERNOV 1909). One and a half hundredweight was brought up from a depth of 4—6 metres in a single 10 minute sweep. In depths of from 3—4 metres the weed could sometimes be seen lying on the bottom if the surface of the water were smooth. The colour of the weed varied from olive brown to dark red-brown according to the depth. It appears that masses of unattached weed have been a feature of this locality for a long period of time.

Fig 2.
A small diesel trawler typical of the fishing fleet at Bønnerupstrand. On deck can be seen the considerable quantity of *Furcellaria fastigiata* f. *aegagropila* brought up in a single short haul.

The dredged material (Fig. 2) was examined and found to consist of about 99% of healthy *F. fastigiata* almost entirely of the forma *aegagropila* with one or two fragments of the attached form, together with a few small plants of *Rhodomela confervoides*, *Polysiphonia elongata* (HUDS.) HARV., *P. nigresens* (SM.) GREV., *Brongniarella byssoides* (GOOD. et WOODOW.) and one individual of *Polyides caprinus* (GUNN.) PAPENF. The plants of *Furcellaria* had epiphytes which included *Ceramium rubrum* (HUDS.) AG., *C. diaphanum* (LIGHTF.) ROTH., *C. fastigiatum* HARV., *Sphacellaria cirrosa* (ROTH.) AG., *Melobesia farinosa* LAM., and basal parts of *Cystoclonium purpureum* (HUDS.) BATT. Other epiphytes included an abundance of many marine diatoms and encrusting and sedentary animals often in large

numbers; for example *Spirorbis borealis*, *Pomatoceros triqueter* L., *Electra pilosa* (L.), *Tubulipora lobulata* HASSALL, *T. plumosa* THOMPSON, *Flustrellidra hispida* FABRICIUS, *Mytilus edulis* and occasional hydroids and tube building annelids. Most of these species and also *Escharella ventricosa* (HASSALL) and *Callopora aurita* (HINCKS) occasionally found on the weed, are characteristic of sublittoral situations.

The dredged weed occurred in loosely tangled clumps and showed no evidence of having been lifted or torn from an attachment. It contained specimens of all sizes from just under 1.0 cm. to 16.0 cms. in length with an average of 6.0 cms. Fully grown plants varied from 9.0—16.0 cms. in length and were therefore short compared with attached plants which normally attain 15—25 cms. in the same neighbourhood, at Gerrild for example. They were invariably richly branched (Fig. 3), the number of ultimate ramuli originating from a single basal ramulus, being in consequence very large. For instance, when 10—11 dichotomies occur in a plant 10 cms. long, a very bushy individual with over 300 terminal ramuli is produced. The diameter of the thallus varied from 0.4 to 1.2 mms. and was much less than that of British plants or of attached plants growing in the same vicinity at Karlby Klint and Gerrild Klint (Fig. 1), viz. 1.4—3.2 mms.

The best formed plants appeared radially symmetrical, a central or proximalol der portion, with younger radiating peripheral, ramuli, giving the specimens a globular or ball-like outline (Fig. 3a). These features are also well illustrated in the bushy plants figured by ROSENVINGE (1917, fig. 91) and LAKOWITZ (1929, fig. 511). The branching of many individuals, however, showed evidence of disturbance of the regular dichotomy characteristic in the attached form of the species (Fig. 3b). The intervals between dichotomies were sometimes markedly irregular and the haphazard production of adventitious branches of various sorts, resulting chiefly from wounding of the thallus, was not uncommon. Ill-formed hapteron-branches were sometimes found, commonly produced at the bases of the adventitious branches just mentioned (Fig. 3a, h), and these hapteron-branches in a few cases touched and attached firmly to another plant leading to an even closer entanglement of individuals (cf. tendrils in *Halopitys pinastroides*, SCHILLER (1909)). Rarely, poorly developed haptera were seen at the true 'base' of a plant giving it an appearance like that of the attached form. A few such plants appear to have been recently detached from a normally attached population, but the others may have been produced by the detachment from the parent thallus of the adventitious branches together with hapteron-branches described above, or as a result of such plants having lain for some

Fig. 3.

A well developed plant from the material dredged at Bønnerupstrand shown alongside (3b) a typical attached plant from the sublittoral fringe in Cardigan Bay. Numerous 'proliferations' can be seen on the upper parts of the thallus of the Danish plant. The British plant bears small regenerated outgrowths at the ends of recently truncated apical ramuli. These different types of regenerative outgrowth can be seen more clearly in the magnified portions shown as insets above the respective plants. A small hapteron-branch developed at the base of an adventitious branch is seen at h.

time in an upright position in the weed mass. Although plants such as these may be regarded as intermediate between the forma *aegagropila* and the normal attached form, they are easily distinguished from the latter by their profuse patent branching and narrow delicate thallus. Moreover, BURROWS (1958) reports that hapteron development in *Laminaria digitata* (HUDS.) LAM. proceeds in detached plants in the field and in culture; hence haptera need not be regarded as a certain indication of recent attachment to a firm substratum.

A special, more regular, type of adventitious outgrowth occurs

very commonly in this material and was reported by ROSENVINGE (1917) as abundant on plants from the more southerly Danish waters (Fig. 1). These very small outgrowths are best called lateral proliferations (Fig. 3a inset). They appear to be more or less transient in nature since they do not form part of the branching system of the thallus and they arise, usually, in considerable numbers, from the upper (outer) parts of the plant (Fig. 3a). They are very characteristic in appearance, being closely set and of very small diameter, as seen in the enlarged figure 4. They appear to be easily detached, thenceforth functioning as 'propagulae' contributing to the vegetative propagation of the unattached plant (see below).

A distinctive and important feature exhibited by the forma *aegagropila* is its sterility. No fructification of any sort was seen throughout the large numbers of specimens dredged at Bønnerupstrand nor amongst the harvested weed in storage vats at the factory at Skibet or in samples of dredged material received periodically from Denmark. However, attached plants from Gerrild, Knudshoved and Stenshoved, all within 6—15 kms. of the harvesting grounds and collected at the same time, had abundant fruiting ramuli.

Since this unattached weed from the southern Kattegat displayed fairly consistent characteristics, a number of typical forma *aegagropila* plants were investigated cytologically by means of an iron-alum aceto-carmine staining method described elsewhere (AUSTIN 1959 a). All the plants examined were found to be diploid with $2n = 68$ chromosomes. It would be unwise to conclude that all the unattached plants are necessarily diploid, but from this evidence it seems that the greater part might be. Possibly, the slightly greater vigour of the diploid thalli as manifest in the attached form is a factor which enables the diploid phase (AUSTIN, 1959 b) to dominate the floating mass.

The presence in the dredged weed of a few plants with a habit more or less intermediate between that of the attached form and that of the forma *aegagropila* was pointed out by ROSENVINGE (1917). My observations confirm this, but suggest that such plants are rare and, furthermore, appear to have been recently detached. The suggestion (cf. LUND & BJERRE-PETERSEN, 1952) that the forma *aegagropila* originates from plants detached from benthic habitats must, however, be treated with caution. Though it seems likely that, in suitable conditions, formerly attached plants can survive and grow in the free unattached state (indeed the forma *aegagropila* must have originated in this way), most of the unattached plants at present in Aalborg Bay may well have originated directly from unattached material either by fragmentation or by the production of the proliferations or 'propagulae' already mentioned.

(i) Fragmentation.

Fragmentation accounts both for a small addition to the weed mass of plants originally attached, and also for an increase in the number of loose lying plants when they themselves break up due to degeneration of older parts. This latter process is to be expected under the prevailing conditions, since the lower parts of the plants which often come in contact with the muddy sand at the sea bottom would eventually degenerate and cause the plant to break up. However, if this, together with the gradual addition of plants cast up from normally attached populations, were the only process by which the weed multiplied, it would seem difficult to account for the continued abundance of the unattached weed despite at least 10 years of steadily increasing harvesting for agar. Furthermore, the free unattached population is made up of plants of all sizes. If degeneration and approximately equal disjunction at the oldest part of the thallus were the principal method of multiplication, then the smallest plants would presumably be no smaller than half the average size of the large plants. This, however, is not the case. Finally, very few plants having the appearance of being recently attached have been found in this free floating weed.

(ii) Regeneration and Proliferation.

Regeneration can take place at almost any point on the thallus where wounding has occurred or the shedding of a fertile organ has taken place. Attention was drawn by GOODENOUGH & WOODWARD (1797) and DAWSON TURNER (1802) to the annular markings upon plants of *Furcellaria* in which such regeneration had occurred. KÜSTER (1899) working on wound healing and regeneration in marine algae listed *Furcellaria* along with other species in which he had observed such phenomena, and DENYS (1909) gave some account of the formation of scar tissue and subsequent new growth in both *F. fastigata* and *Polyides caprinus*.

However, it was ROSENVINGE (1917) who noted two types of adventitious outgrowth produced on the thalli of *Furcellaria* from the Danish waters, some of which was the forma *aegagropila*.

One type of outgrowth originates from scars left by the shedding of sporogenous apices after fruiting in late winter or by the truncation of the thalli by other means. These regenerated branches are often found on the typically attached plants of *Furcellaria* (Fig. 3b, inset) and resemble closely those found in *Polyides* (RAO, Thesis 1954) and other marine algae. They are best called axial regenerated branches because they grow out to form an integral part of the branching system of the thallus and, furthermore, arise by the active division of

Fig. 4.

A close-up of parts of the ultimate ramuli of plants of the Danish forma *aegagropila* showing below, the appearance of numerous very young outgrowths or proliferations over the surface of the thallus, and above older proliferations which have almost reached the maximum size which they attain whilst still attached to the parent thallus. The insecure unions between the main thallus and the proliferations are shown at 'x'.

cells of the axial filaments which form the central structural core of the thallus (Fig. 5b).

Between two and six weeks after truncation a broadly based obconical papilla(e) appears (Fig. 5b) and elongates into a new ramulus. This regenerated branch can be identified, often after a considerable period of time (1—2 years), by the ring or ridge left at its base due to the difference in girth of the old and the first new growth. Up to eight to ten regenerations may occur side by side on a single truncated ramulus, but more often they arise in ones and twos. They have been produced on decapitated ramuli under cultural conditions; in winter visible papillae appeared in 3—4 weeks, and reached 0.4—0.6 mms. in length in 6—8 weeks and an average length of 1.8 mms. in 3 months (Austin 1960).

The other type of regenerative outgrowth are the lateral proliferations referred to above (p. 262). These occur on localised regions of the thallus from about 1.0—3.0 cms. below the apical ramuli (Figs. 3 and 4) and appear to be confined to the unattached *F. fastigiata* forma *aegagropila*.

Unlike the axial regenerated branches they develop from groups of superficial cells which form very tiny papillae (Figs. 4). The latter rapidly increase in girth as they grow out, so that their diameter soon becomes greater distally than at its plane of insertion on the thallus (Figs. 5a and 6). As a result, they are readily broken off.

Without close examination of these plants *in situ* throughout the year, it is impossible to discover the stimulus leading to the production of these proliferations. It seems unlikely that chance wounding by browsing animals could be the cause of their initiation, because they occur over a small and fairly well defined part of the thallus. It seems more likely that the growing apices of the plants become abraded against the sandy bottom as the weed clumps sway and roll with the movements of the water, and the scarring of the apical meristematic surface so caused might result later on in the proliferation of the small lateral ramuli. Such change and subsequent regeneration would be most likely to occur during the season of rapid growth, and, if so, the scars would soon be left some way below the growing apices. The proliferation would in consequence appear below the top of the thallus, and this is where, in fact, they are found.

The proliferations themselves are much narrower than the parent thallus attaining a girth of only 0.2 to 0.6 mms. (Figs. 4 and 5), and have a more simple, less well differentiated construction, lacking notably a medullary region of axial filaments (Fig. 5b). Typical proliferations only reach a limited size whilst attached to the parent thallus and very rarely dichotomize, but frequently, when they have only attained a length of 1 to 2 mms., small papilla or secondary pro-

liferations appear on their basal parts (Fig. 5a). These rudiments develop into minute branches at the base of the proliferations.

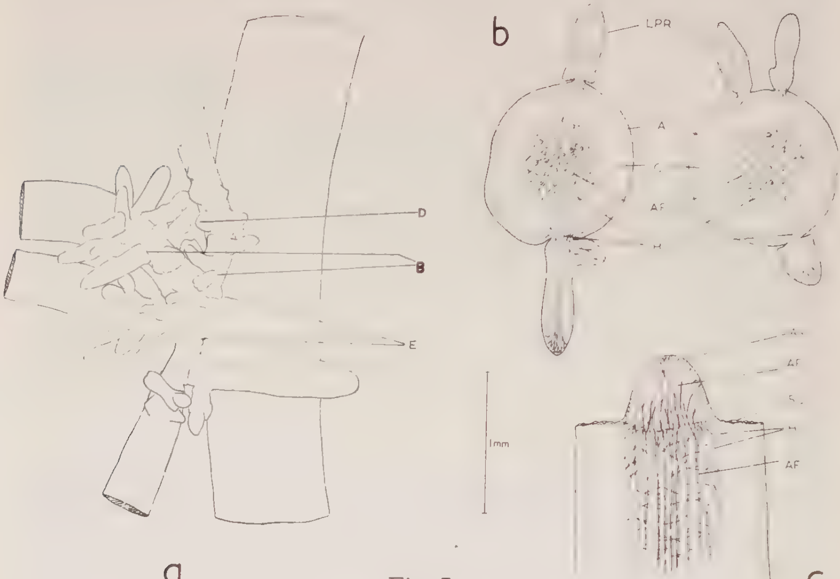

Fig. 5.

5a. Drawing of the base of a cluster of 'proliferations' on a dredged plant of *F. fastigiata* f. *aegagropila*. At B and D very small secondary outgrouwths or 'proliferations' can be seen to be developing. At E the narrow constricted union between 'proliferations' and the main thallus can be seen.

5b. Diagrammatic representation of transverse sections of the thalli of the f. *aegagropila* at points where lateral proliferations (LPR) arise and below, (5c), a longitudinal section of the early stages in the growth, on the thallus of an attached plant, of an axial regeneration (AR). In the latter the continuity of the axial filaments (AF) between parent thallus and regenerated outgrowth can be seen, whilst no such continuity is obvious in the case of the lateral proliferated outgrowths on the transverse sections above. A = assimilatory cells; C = cortex; H = hyphae; SC = scar tissue.

The following facts suggest that, when the proliferations reach a certain size, they become detached at the base from the parent thallus and develop into new plants:

(i) The union at the junction between parent thallus and proliferation is too narrow and too weak to support a larger structure (Figs. 4 and 5a, b).

(ii) Large proliferations are never found on the thalli. These would be expected if they continued their development without detachment. A maximum length of 6—7 mms. may sometimes be reached whilst still attached, but the girth remains very small and dichotomy does not occur (Fig. 4).

(iii) Large numbers of these small detached proliferations are found in the jars in which material was stored and preserved; since the material had not been handled, they had evidently dropped off readily.

(iv) Specimens which appear to have developed from the detached proliferations or 'propagulae' can be found in dredged material. These plants can be distinguished by their appearance; they often possess dense radical branches and a ring-like zone of outgrowths, some haptera-like, round their basal parts. Occasionally these small plantlets have already developed small proliferations on the upper ramuli (Fig. 6).

Although it is possible that these lateral proliferated branches are produced as a reaction to some form of wounding, anatomical investigation shows them to be rather different from the usual type of regeneration thus produced (KÜSTER 1899). The latter arise by the rapid production of hyphal cells from most of the axial filaments and

Fig. 6.

Plants taken from the weed dredged off Bønnerupstrand and arranged in a hypothetical sequence from the small detached 'proliferation' or 'bulbil' through intermediate stages to plants which will become typical forma *aegagropila* plants after some increase in size.

innermost cortical cells situated below the wounded surface (Fig. 5c), at which a layer of thick walled 'scar' cells are formed (AUSTIN 1960) The rapidly growing cells burst through this layer and grow out as a broad based papilla (Fig. 5c). The hyphal cells, continuous with the axial filaments of the parent thallus, become the axial filaments of the new regenerated branch and the structure of the latter is soon identical with that of the former. The lateral proliferated branches, on the other hand, spring from a very small area on the surface of the thallus and involve only the outermost layers of the thallus. The diagrams of sections of the thallus shown in Fig. 5b illustrate this; the elongated 'cell rows' passing into the new outgrowth are a result of the elongation of hyphal cells produced in the cortex of the parent thallus. The axial filaments do not contribute to the formation of these lateral proliferations as they do in the axial regenerations and as they do in the formation of a dichotomy in the thallus.

It may well be that, until the new regeneration can develop axial filaments, and hence the typical structure of the parent thallus, it cannot increase in girth to any extent. By the time it has been able to develop mature structures the increasing stresses at its junction with the parent thallus here brought about its detachment.

Although KÜSTER (1899) dealt mainly with regenerations of the first (axial) kind, arising as a result of obvious wounding, he describes one instance — in *Padina pavonia* (L.) LAM., — where tiny proliferated branches of the second (lateral) kind are produced and it is interesting to note that these are a means of vegetative multiplication in the species.

F. FASTIGIATA FORMA AEGAGROPILA AND OTHER POPULATIONS OF UNATTACHED SEAWEEDS

Although *F. fastigiata* in the unattached state is not uncommon in other parts of the Baltic (WAERN 1952), it is in the Danish and German waters that the forma *aegagropila* reaches its most abundant and characteristic state and can most clearly be regarded as an ecotype of the species.

Populations of unattached seaweeds of other species are known and it may be significant that these seaweeds and the environments in which they occur have certain features in common. These features will first be exemplified by a brief resume of the occurrence of free floating forms of *Gracilaria verrucosa* (HUDS.) PAPENF. in Australia, in S. Africa, in N. Carolina and in Norway, of *Phyllophora nervosa* (D.C.) GREV., in the Black Sea and of the pelagic *Sargassa* of the Sargasso Sea, in addition to SCHILLER'S (1909) "Migrationsformationen" of the Adriatic.

Loose lying pupulations of the cosmopolitan alga *G. verrucosa* occur in certain parts of Australia (WOOD 1946) and in North Carolina (HUMM 1944). Populations of attached and unattached plants occur in the same vicinity. Attached plants are fertile, bearing normal sexual and asexual organs, whilst the more abundant unattached plants are sterile and increase solely by vegetative means. In addition, according to HUMM (1944), the loosely drifting plants continue to grow. Similarly, from the sheltered localities in Norway where *G. verrucosa* occurs, STOKKE (1957) mentions that there is a greater abundance of unattached sterile plants than of the normal attached plants which are fertile. This author states that the thallus of the unattached plants is significantly thinner than that of the attached plants from the same locality. He also notes that some specimens have many short branches and are without any definite thallus axis, and that they multiply vegetatively largely by fragmentation. These differences form a close parallel with those observed between the unattached *F. fastigiata* forma *aegagropila* and the attached plants found in Aalborg Bay in Jutland. The large quantities of *G. verrucosa* in the Saldanha-Langebaan lagoon in S. W. Africa appear to survive in the unattached state (ISAAC 1966), but it is not clear whether these plants exhibit any characteristics not present in the attached plants in the lagoon. The best known example of a population of unattached seaweeds is that which gives its name to the Sargasso Sea. The species of *Sargassum*, which constitutes this vast pelagic vegetation, differ from the unattached forms described above in that they float in the surface layers of the sea on account of the buoyancy of their air bladders. The waters in which they occur are not shallow and, indeed, loss due to sinking of non-buoyant weeds is one of the ways in which this floating vegetation is depleted (PARR 1939). Despite these differences, however, the plants exhibit the following significant similarities with other instances of unattached communities of weed. Their form is quite distinct from that of attached benthonic *Sargassum* species from which they presumably originated. They are more diffuse in habit and lack the usual polarity of the attached plants; they are quite sterile and they multiply, as far as is known, only by fragmentation and continued growth in the pelagic state.

Only brief references can be made to the unattached forms of algae which SCHILLER (1909) found in the Adriatic. Over a dozen species, including green, brown and red algae, were described by this author. It is significant that the features common to all the forms he described are the same as those possessed by the unattached algae mentioned above, namely — they are never attached, have no primary attaching organ, and are always sterile. Furthermore, some of the unattached forms in the Adriatic, such as *Cystoseira barbata* J. AG., *Halopitys*

pinastroides (GMEL.) KÜTZ, *Rytiphloea tinctoria* (CLEMENTS) C. AG., *Chondria tennuissima* (GOOD et WOODW.) AG. and *Gigartina acicularis* (WULF.) LAMOUR, exhibit profuse patent branching of a thin, sometimes fine and delicate thallus, forming ball-like masses. SCHILLER reported large quantities of these unattached forms at certain localities and postulated vegetative multiplication, together with the addition of individuals from situations where they occur attached, as the means of propagation of these concentrations of weed.

Cladophora species are amongst the loose lying forms found in the Adriatic and the unattached *Cladophora*-balls or *aegagropila*-forms of this genus are described by ACTON (1916). As in the ball-like forms of *Vidalia volubilis* (L.) J. AG. and *Valonia utricularis* (ROTH.) AG., no reproductive structures are formed and multiplication takes place vegetatively by the production of small buds or 'daughter-balls' (SCHILLER 1909).

Various authors (SVEDELIUS 1901; SCHILLER 1909; REINKE 1889) have noted the sterile unattached thalli of certain Fucales which occur in large numbers as loose lying forms in the sublittoral of quiet landlocked seas. Mention may be made of *Chondrus crispus* f. *aegagropila* (ROSENVINGE 1931), *Ascophyllum nodosum* f. *scorpioides* (HORNEM.) HAUCK. and *Fucus vesiculosus* f. *lutarius* CHAUV; the latter produces, on the parts of the thalli lying on or buried in the muddy substratum, numerous small and closely set adventitious branches which, as they become free by the decay of the stalk, bring about multiplication (SAVAGEAU 1908). Similar closely set adventitious branches are figured by ROSENVINGE (1931) on the loose lying *Chondrus crispus* f. *uncinata* LYNGB.

Finally, a loose lying sublittoral algal population has recently been described from Port Erin Bay in the Isle of Man (BURROWS 1958). It appears, however, that this admixture of algal species, most of which have their origin in the attached sublittoral populations in the vicinity, has few of the features which are common to those of the communities described above and should not be regarded as analogous. It is not self perpetuating in the loose lying state, but depends upon the development of minute sporelings on sand and gravel on the floor of the bay (i.e. upon the existence of an attached phase), which subsequently becomes detached and continues development. BURROWS found that detached sporelings grow to a considerable size in laboratory culture while retaining most of the characters of the attached plant. This is quite a different situation from that which would obtain if the detached plants would proliferate independently of the substratum.

A brief summary of the environmental conditions prevalent where the unattached algae are found may serve to elucidate the factors which govern their occurrence.

Hydrographic features appear to play a dominant part in the distribution of the unattached forms. They occur, most commonly, in land-locked seas, but also in shallow inlets or in quiet bays and estuaries. In these situations residual currents may either be absent, resulting in stagnation or semi-stagnation as in the Norwegian inlets, and some of the Baltic and Adriatic localities, or take the form of circulating currents such as occur in the Sargasso Sea, parts of the Adriatic and in the southern Kattegat (LUND & BJERRE-PETERSEN 1952). Locally undisturbed areas may also occur in the angle subtended by two converging streams of water; this phenomenon has been suggested as the feature governing the occurrence of *Phyllophora nervosa* in the Black Sea (SERNOV 1909). From the literature, it appears that these particular hydrographic conditions may be very stable — the unattached algae of the Sargasso Sea, of the Black sea and of the Danish Waters have been recorded for a very long period of time — or on the other hand they may be less stable allowing only the development of temporary populations of unattached weed, such as the loose lying *G. verrucosa* in Australia and North Carolina. These communities are said to fluctuate considerably in quantity according to the season as well as being liable to destruction by exceptional storms in open shallow waters or by floods or 'flushes' in estuarine habitats (NEWTON 1949).

Of the environmental factors, it is unlikely that temperature is responsible for any of the features exhibited by the unattached plants, for the latter often occur close to the attached plants and in waters with exactly similar conditions of temperature.

The same can be said of salinity, although it may be significant that, in many of the areas in which these free floating weeds occur, due to their sheltered partly land locked situations, the salinity is lower than that found where the species normally occur attached exposed rocky coasts; for example, the Black Sea (17‰—20‰), the true Baltic (less than 10‰), the Danish waters (between 20‰ and 30‰), Norway's shallow inlets and the estuarine conditions where *G. verrucosa* occurs in Australia and S. Africa, and finally the lagoons and inlets of the Adriatic. However, it has been shown that most of the species under discussion can tolerate considerable fluctuations in salinity. That *Phyllophora* and *Furcellaria* can live and grow in water of very reduced salinity is evidenced by their deep penetration of the Baltic, and the ability of species such as *Ulva*, *Cladophora* and

Chaetomorpha to tolerate a wide range of salinities is well known. STOKKE (1957) records *G. verrucosa* in localities with salinites of 10‰—30‰, with 20‰ as a common value, although CAUSEY *et al* (1946) found that in North Carolina the optimum value for growth of this species lay between 25‰ and 35‰. It appears then that this species is somewhat less tolerant of low salinity than is *Furcellaria*. Attendant upon conditions of semi-stagnation, concentrations of H_2S tend to be high, due to anaerobic bacterial activity. Tolerance to considerable amounts of dissolved H_2S has been demonstrated for *G. verrucosa* (STOKKE 1957) and, considering the conditions in which they grow, tolerance to H_2S is probably high in the unattached populations of *Phyllophora nervosa* and *F. fastigiata* f. *aegagropila*.

Although there is no explicit data, conditions of illumination in the loose lying weed masses appear to be little different from those of attached populations at corresponding levels in the sublittoral of rocky shores. However, some of SCHILLER'S (1909) unattached forms sometimes occur underneath a layer of another free floating alga, or even partly covered by mud and may thus receive low light intensities. The *Phyllophora nervosa* of the Black Sea occurs at a depth of from 14—15 fathoms, a depth at which it is rarely found attached, though this may be due to the paucity of rocky substrata at these depths. Conversely the *Sargassum* spp. of the Sargasso Sea live in the surface of the water and receive a total illumination probably greater than their benthic counterparts on rocky shores.

It is clearly difficult to name any factor or group of factors which may be responsible for the peculiarities exhibited by loose lying forms, save perhaps the one common to them all, namely that they are unattached. That this is their most important feature seems to be suggested when the problem of origination of the loose lying forms is considered. Only for the Sargassa of the Sargasso Sea has this problem been successfully resolved. PARR (1939), with the support of a very great deal of evidence, concluded that 'the pelagic *Sargassum* population is essentially a self-sustaining unit with a potentially infinite longevity and a very long normal expectancy of life for its individual plants, receiving (at most) only a very slight annual contribution from benthonic vegetation merely sufficient to compensate for its own loss by a slight excess of mortality over vegetative growth increment.' Although this author believes that at one time the pelagic form originated from detached benthic plants, these do not form the present weed mass by their periodic dislodgement from rocky shores. From the observations made on *F. fastigiata* forma *aegagropila* set out in the proceeding sections, it is suggested that this population of loose lying weed has much in common with the free floating *Sargassa* and that PARR'S statement may hold good for both. It seems quite

certain that prolonged life in the unattached condition results in the adoption of a certain form and habit, accompanied by sterility, which distinguishes these plants from their attached counterparts.

The environments in which these changes take place possess the following characteristics. There is no firm, stable substrate for the settlement and development of the sporogenous products of sexual reproduction. Commonly the plants lie on or near the soft, mobile, sandy or muddy bottom and are covered by a depth of water which allows penetration of light sufficient for assimilatory requirements. Under these conditions, which are wholely unsuitable to normally attached algae, few species are able to make use of the environment, but those which can are likely to dominate it. The essential adaptions required for survival appear to be:

1. The plant must be able to live and grow without attachment.
2. The plant must be able to live without constant orientation to light or gravity, as it is likely to be continually moved in position.
3. The thallus must withstand being rolled over the sea bed and being partially buried in mud or sand.
4. It must be able to regenerate independently of attachment to the substratum. This implies vegetative reproduction, since in attached algae the sexual and asexual reproductive products invariably require a firm substrate for settlement and growth. Such vegetative multiplication should be able to proceed without clonal decay.

It follows from these conditions that the ideal plant should be radially symmetrical and have a springy resilient bush-like thallus capable of continuous vegetative regeneration. It should be firm and not easily damaged by scouring. A narrow wiry thallus would be advantageous for it would lead to form of a matted, light, ball (cf. *Cladophora*), with adequate water exchange throughout, and with a large assimilatory surface in relation to its volume.

Unattached forms (of attached algae), which exhibit these adaptations and multiply vegetatively for long periods of time, may tend to loose the ability to form holdfast structures and sexual organs. It is interesting to record the discovery of one large plant of *Polyides caprinus* dredged up with *F. fastigiata* f. *aegagropila* at Bønnerupstrand in 1958. This plant had many of the characteristics of the unattached form of *Furcellaria* and could be said to be approaching a forma *aegagropila* of *P. caprinus*. It may be that these forms are on their way to becoming new species. The environment may be unstable, in which case polymorphism of attached and unattached froms is evolutionarily desirable. The attached form, say after severe storm damage, can repopulate the area. Otherwise it is hard to understand

why this niche is not occupied by a monomorphic unattached seaweed like the free floating *Sargassum*.

The actual species which constitute the loose lying communities clearly depend upon the availability of potentially suitable species in each region. It is possible that numerous situations, which are favourable for the support of loose lying algae, exist in regions where potentially suitable species are absent and could be used for algal production if the appropriate species were introduced.

Summary

The unattached populations of *Furcellaria fastigiata* forma *aegagropila* in Danish waters exhibit characteristics which are paralleled to a remarkable degree by those possessed by communities of unattached algae in other parts of the world. These characteristics include sterility, multiplication by vegetative means, and the adoption of a form, devoid of holdfast organs, which commonly has a globular or subglobular habit suited to rolling about on the sea bottom. Branching is often profuse and patent and may be accompanied by a thallus diameter far smaller than that of the attached form. Vegetative multiplication may be effected by fragmentation, and, as in *F. fastigiata* forma *aegagropila*, by small accessory lateral branches which function as ‚propagulae.' The latter originate in a manner somewhat different from that of the axial regenerated branches produced on decapitated thalli and on thalli which have been more than superficially wounded. Evidence suggests that much of the unattached population of this latter species in the central Kattegat is made up of diploid thalli.

All loose lying forms ultimately originate from attached species, which possess or can adopt certain characteristics which enable them to survive in the unattached state.

Résumé

Les colonies sans attaches de *Furcellaria fastigiata* forma *aegagropila* dans les eaux danoises montrent des caractères qui sont parallèles à un degré remarquable à ceux possédés par d'autres communautés d'algues flottantes dans les autres parties du monde. Ces caractères comprennent la stérilité, la multiplication par des moyens végétatifs, et l'adoption d'une forme, dépourvue d'organes de préhension, généralement sphérique ou quasi sphérique, adapté à se mouvoir sur le fond de la mer. La formation de branches est souvent abondante et évidente et peut être accompagnée d'un diamètre thallique bien plus petit que celui de la forme fixe. La multiplication végétative peut être effectuée par fragmentation, et, comme chez *F. fastigiata* forma

aegagropila, par moyen de petites branches latérales accessoires qui fonctionnent comme des 'propagulae.' Ces dernières prennent leur naissance d'une manière quelque peu différente de celle des branches axiales régénérées produites sur thalles décapités et sur thalles qui ont été plus que superficiellement blessés. L'expérience suggère que beaucoup de colonies flottantes de cette dernière espèce dans le Kattegat central sont formées de thalles de forme diploide.

Toutes les formes libres et flottantes prennent leur origine en dernier ressort des espèces fixes, qui possèdent ou peuvent adopter certains caractères qui leur permettent de survivre dans l'état de liberté.

Acknowledgments

I am grateful to Professor Lily Newton for her encouragement whilst working in Aberystwyth and to Dr. D. J. Crisp for his many helpful criticisms and suggestions, particularly in relation to the section dealing with unattached seaweeds, and in the preparation of the manuscript for publication. I wish also to thank Herr Risenby and Herr Fuglede of the Scandinavisk Agar Industri for sending me material of *Furcellaria fastigiata* f. *aegagropila* and for arranging for me to make collections by dredging with the harvesting vessels in the Kattegat. Dr. Joyce Simpson of Bangor kindly prepared the summary in French.

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Mise au point de systématique dans le genre Lesquereusia

par

L. Decloître

Lesquereusia inaequalis Cash-Hopkinson

et

Lesquereusia spiralis var. *inaequalis* Playfair.

1° *Lesquereusia inaequalis* Cash-Hopkinson.

Voici la description donnée par les auteurs dans British Freshwater Rhizopoda and Heliozoa, Tome II, pages 72—73, planche XXIII, figure 12: „Larger than average examples of *L. spiralis*, similarly constructed but less elegant; differing mainly in the outline of the test, which is relatively much broader, and in side view is divided roughly by a shallow depression on the dorsal surface into two turgid unequal portions. The measurement across the test in its broadest part exceeds, as a rule, that taken longitudinally from the extremity of the neck to the crown. The test is chitinous, transparent, and covered externally with the same interlacing curved „rods" as in *L. spiralis*-these, if anything, being longer and thinner. It has a short neck, which is sharply truncated; the mouth not contracted. The upper surface of the neck has two slight elevations which give it a wavy outline. Nucleus and pseudopias as in *L. spiralis* generally simple.

Dimensions: length 135 μ (from mouth to summit of test); breadth 125 μ.

At Dunham, Cheshire, amongst Sphagnum, 1904 and later, associated with others of this genus.

Were it not for the appearance of this peculiar *Lesquereusia* year by year, we might regard it as an abnormal form of *L. spiralis*. It has, however, characters quite distinct examined. It may be at once differentiad from the last-named species by the peculiar, unequally

balanced test. Like others of the genus the animal is usually very active."

On voit par ces lignes que les auteurs ont hésité entre, en faire une espèce autonome ou en faire une variété de *L. spiralis*; mais, ce qui est, pour le moment, particulièrement utile à noter, c'est que les thèques sont recouvertes d'éléments identiques dans les deux cas.

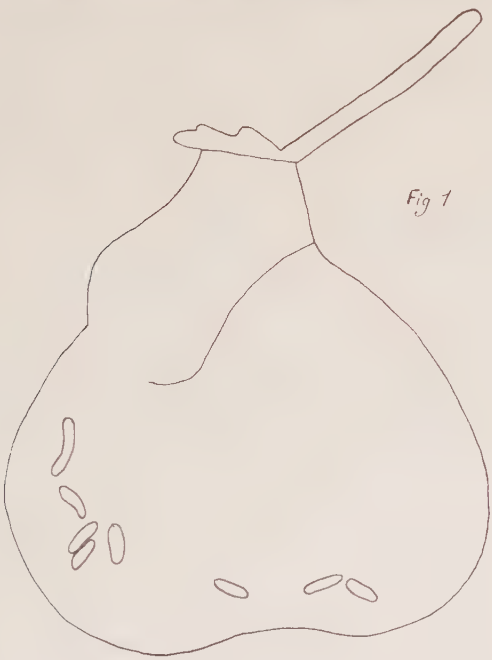
2° *Lesquereusia spiralis* var. *inaequalis* PLAYFAIR.

Cet auteur a décrit cette variété dans „Rhizopods of Sydney and Lismore" paru dans Proceedings of the Linnean Society of New South Wales 1918; planche XXXVIII figure 2. „Test very much smaller than usual, dome flattened above and humped towards the side of the orifice. Cf. *L. inaequalis* CASH II, page 72, Pl. XXIII, figure 12. Length 91 breadth 91. Lismore (316)."

Or, si l'on examine en détail le dessin donné par PLAYFAIR, il est clair que la thèque n'est pas une thèque de *L. spiralis*, irrégulière, mais que c'est une thèque de *L. modesta* RHUMBLER.

Cette variété, admise, ne peut rester dans la nomenclature comme une variété de *L. spiralis*. Il faut la considérer comme une variété de *L. modesta*.

Nous aurons donc les deux cas suivants: *Lesquereusia inaequalis*



Lesquereusia inaequalis selon CASH

Cash-Hopkinson, avec comme habitat sphagnum et répartition biogéographique: Angleterre. Fig. 1.

Lesquereusia modesta var. *inaequalis* (Playfair) Decloître, comb. nov., ex *L. spiralis* var. *inaequalis* Playfair, avec comme répartition biogéographique: Australie et A.O.F. (Decloître, sous le nom *L. spiralis* var. *inaequalis* Playfair). Fig. 2.

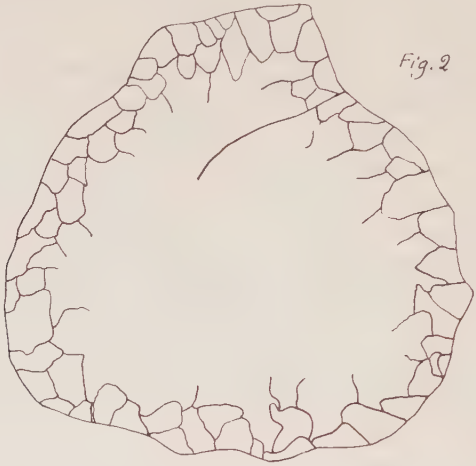


Fig. 2

Lesquereusia spiralis var. inaequalis

selon PLAYFAIR

Hydrobiological Studies on the Tugela River System

Part I. The main Tugela river

by

W. D. Oliff

CONTENTS

1. Introduction.

A survey of the Tugela river system in Natal is being undertaken by the South African Countil for Scientific and Industrial Research on behalf of the Natal Town and Regional Planning Commission. Its purpose is the determination of physical, chemical, and biological conditions in the rivers of the basin. As the area of the basin is 11200 square miles, this is a vast undertaking. The work to date has been limited to a survey of the main river together with some aspects of its tributaries. Further investigations of the trubitaries are in hand, and the results of these will be complementary to those already completed.

This paper presents the results of work on the main river, and covers the period between October 1953 to June 1955.

2. Description of the basin.

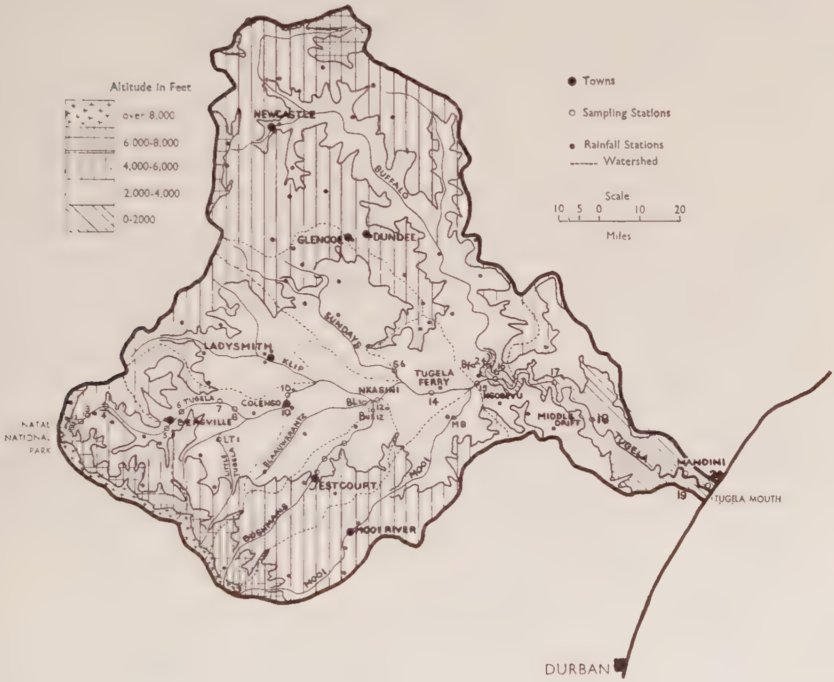
(a) Topography.

The topography of the basin has been described in detail in the Natal Regional Survey published by the University of Natal, 1951. The main physical features are indicated in Figure 1.

The basin occupies the central third of Natal, between the Drakensberg mountains on the west and the Indian Ocean on the eastern coast of South Africa. Within a few miles of the source, the mountains fall away rapidly to a wide, gently sloping, shallow valley which extends roughly half-way down the basin. Below this, the valley is incised by younger river valleys and the topography is rugged and hilly,

except for very narrow bottom lands at places on the banks of the rivers. The lower part of the basin in the Ngobevu-Mfongosi area, is also very rugged and broken, but towards the coast the valley widens, and rolling hills descend to the sea.

Figure 1
The Topography of the Tugela River Basin



(b) **Catchments.**

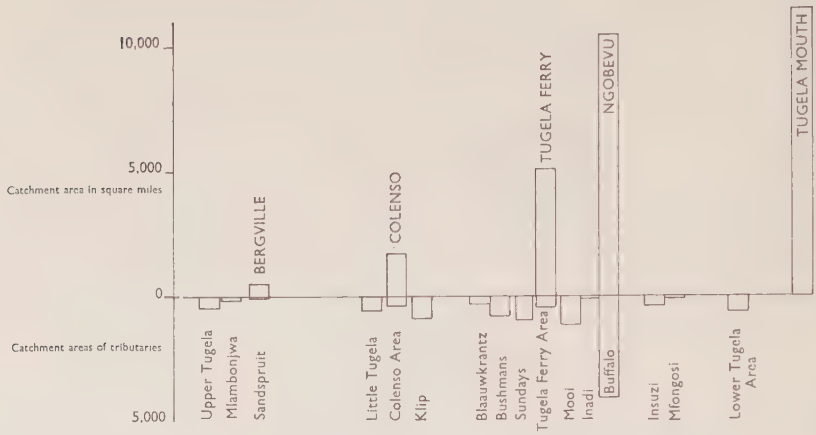
The 11,200 square mile basin comprises eight major catchments. These are, in order downstream:

The Upper Tugela (above Bergville)
The Little Tugela
The Klip
The Bushmans
The Sundays
The Mooi
The Buffalo
The Lower Tugela

Table A. 1. (in appendix) details the areas of all the catchments in the basin, and Figure 2 illustrates their areas and the order in which

they join the river. It will be seen that the Buffalo is the largest, and in fact, most important single tributary.

Figure 2
Catchment Areas in the Tugela River



(c) **Geology.** (Based on information from du Toit (1954)).

The basin: The upper five-sixths of the basin lie on formations of the Karroo System while the remainder towards the coast lies upon beds of the Primitive System and the Table Mountain Series of the Cape System. The latest lavas of the Stormberg series lie uppermost, and the oldest formations of the Primitive System lie below.

The order down stream is:

i. the basaltic and rhyolitic lavas of the Drakensberg.
ii. beds of the Stormberg series in the foothills of the Drakensberg mountains.
iii. beds of the Beaufort series in the flatter upper half of the basin.
iv. beds of the Ecca series in the middle portion.
v. old granites and gneisses of the Primitive System which have been exposed by faulting in the lower portion.
vi. beds of the Table Mountain series of the Cape System towards the coast.

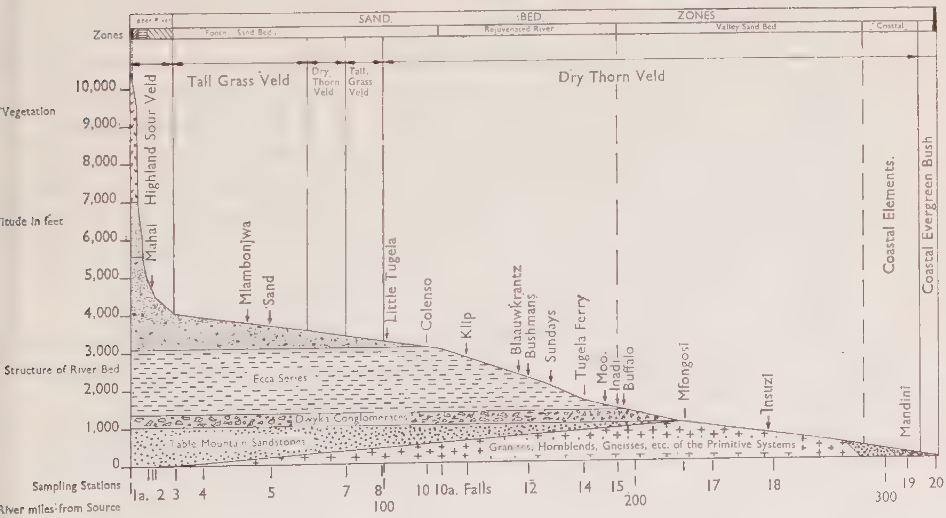
The tributaries: The catchments of most tributaries in the basin, including the Upper-Tugela, -Bushmans, and -Mooi rivers, and the Sandspruit and Venterspruit streams on the western margin of the basin, all commence high on the face of the basaltic and rhyolitic lavas of the Drakensberg. The formations soon change, first to sandstones and shales of Red and Molteno beds of the Stormberg series, at the foot of the mountains, and then to sandstones and shales

of the Beaufort series which underlie the greater part of the catchment away from the mountains, forming a wide shallow valley.

In contrast, the upper half of the Buffalo river catchment, that of the Sundays river in the north, and those of the lower-Mooi and -Bushmans rivers in the south, and the local catchments in the middle of the basin around Colenso, Nkasini and Tugela Ferry, all lie upon rocks of the Ecca series. The lower Buffalo, Mfongosi, Insuzi and Inadi catchments and local areas in the middle and eastern parts of the basin around Ngobevu and Middledrift, all lie upon Dwyka tillite, and the old granites and gneisses of the Tugela and Mfongosi systems. Finally, the more coastward, eastern part of the main river below Middledrift, is composed of rocks of the Table Mountain and Ecca series.

These geological formations influence the character of the water in different sections of the river. The basaltic lavas, the Stormberg beds, and the Upper Beaufort beds in the upper, more mountainous parts of the basin, provide much of the water in the river with little dissolved and suspended material. The Lower Beaufort beds, and Natal Ecca beds, which cover most of the wide shallow valley forming the middle part of the basin, provide water with higher concentrations of dissolved material, comprising largely calcium and magnesium bicarbonates. Considerable amounts of silt also accrue to the river. Finally the formations of the lower coastal part - the Primitive Granites and Gneisses, Table Mountain Sandstones, and Natal Coastal Ecca beds, provide waters with somwehat lower concentra-

Figure 3
Profile of Tugela River



tions of dissolved material than is generally found in the middle part of the basin, though the individual concentrations of chlorides and sulphates are somewhat higher than in other parts.

The characteristics of the various geological series are detailed in Table A2, in the appendix, and the relative positions of the formations are indicated in the profile diagram of the river in Figure 3.

(d) **Climate** (based largely on information from NATAL REGIONAL SURVEY (1951)).

The basin is situated in the subtropics, and its climate is determined by its position and topography.

The are two main seasons distinguishable: the dry, low-flow, winter season, lasting usually from April or June to October, or more rarely November; and the wet, high-flow, summer period which lasts for the remaining months. The dry, low-flow season in 1954 was from June to October inclusive, and the wet, high-flow season from November 1954 to March 1955 inclusive. These periods were used in calculating averages in this paper. Isohyetal and isothermal lines follow a direction parallel to the escarpment, with appropriate deviations where long spurs and river valleys run in an east-westerly direction. Mean air temperatures near the mountains are 7°C. in July, and 18°C. in January, whereas at the coast, the means are 16°C. and 22°C. respectively. Extremes are encountered in the river valleys, particularly in the lower half of the basin, where temperatures reach 32°C. in summer and fall to several degrees below freezing point in winter.

(e) **Rainfall** (based on information obtained from the WEATHER BUREAU, Department of Transport).

i. General. - The basin receives most of its rainfall in summer, though there is, naturally, considerable variation mainly due to differences in topography. The winter is comparatively dry. Heavy rains fall on the highest points of the escarpment — as much as 1905 mm. (75 inches) a year. At lower altitudes the rainfall is considerably less, and in the sheltered valleys and depressions of the lower part of the basin, is as low as 635 mm. (25 inches) a year. The coastal portion of the valley receives somewhat more 1103 mm. (43 inches), but its catchment area is relatively small.

The mean annual rainfall over the whole basin is 843 mm. (33.2 inches). (Estimated from data published by the Meteorological Office in 1945). Rainfall zones in the basin are listed in Table A3 (in appendix). The mean annual rainfall in tributary catchments ranges between 762—940 mm. (30—37 inches), except in the Mlambonjwa and Upper Tugela river catchments, where it is greater as a result of

the exceptionally high rainfall at the face of the Drakensberg escarpment. These two catchments represent only 5.8 % of the area of the basin.

ii. The rainfall during the survey. — Records of the rainfall at 96 stations in the basin were available for the period of the survey. These stations were not randomly distributed, but occurred mostly in the higher rainfall areas where observers were available. (See Figure 1). An average of the rainfall at stations in a particular catchment in the basin thus does not constitute an unbiased estimate of the mean annual rainfall in the catchment. This simple average, however, is the only estimate that can be calculated because of the paucity of data. In a few cases where the coverage was exceptionally poor, some neighbouring stations outside the catchment were included when calculating the average to increase the size of the sample. The long-period average annual rainfall for each area is included for comparison. (Refer W.B. 20). See Table A4. (in appendix).

In general, it appears that the annual rainfall in 1953—54 was average: the lower areas of both the Tugela and its tributaries received 640—662 mm., the middle areas received 660—900 mm., and the headwaters of the Tugela, Mooi, Bushmans and Insuzi rivers in the Drakensberg, and the coastal belt, all received 1,000—1,200 mm. during the year. The rainfall in the year 1954—55, however, was 11 % greater than average, because more rain occurred in October, 1954 and January and February, 1955. The significance of this will be discussed later.

(f) **Vegetation** (based on information from ACOCKS (1953)).

The characteristic vegetation of the Drakensberg escarpment is Themeda-Festuca alpine veld. This is restricted to the high ground bounding the basin, and occurs on Stormberg beds, associated with a high rainfall.

The vegetation of most of the catchments of the upper- Bushmans and -Mooi rivers, and of small areas of the upper margins of the Tugela, Venterspruit, Sandspruit, and Sundays rivers on the plain of Beaufort beds, is highland sourveld and DOHNE sourveld. Some of the higher areas in the lower Buffalo and Insuzi river catchments, are similar. The vegetation of most of the remainder of the upper Tugela, Sandspruit, Venterspruit, and upper Sundays river catchments, is southern tall grassveld. On the other hand, most of the upper part of the Buffalo river basin is somewhat different and has a perimeter of tall grassveld on high ground surrounding the main valley, where the vegetation is sour sandveld. The underlying geological formations are Lower Beaufort beds and the Natal coal measures.

The vegetation of the more broken, hilly, and drier catchments of the lower-Tugela, -Klip, Sundays, Bushmans, -Mooi and -Buffalo rivers upon Beds of the Ecca series, is dry thorn, or valley bushveld. Ngongoni bushveld occurs in some small areas on high ground in the lower river below Ngobevu, and Ngongoni veld of the Natal mist belt occurs on the heights around Kranskop.

Finally, a small area of coastal forest and thorn veld is found on the sandy coastal soils of the Table Mountain sandstones where the rainfall is higher. Most of the rather narrow coastal belt is used for the cultivation of sugar cane.

(g) **River Flows** (based on information obtained from the HYDROGRAPHIC SURVEY SECTION of the Department of Water Affairs).

i. Flow data are tabulated in Tables 1 and A5, A6, A7 in the Appendix and are illustrated in Figure 4.

For the period of the survey the following full flow gauging stations were in operation on the large rivers:

Tugela River at Tugela Ferry.

Buffalo River at de Jagers Drift.

Mooi River at Muden.

There was no gauging station near the mouth and consequently no direct readings of the total discharge.

Since it was necessary to have some estimate of the total discharge, it was assessed in the following way. The known flows at the above stations, which reflect the contribution from 75 % of the catchment of the basin, were summed. To this was added one-third of the sum as an estimate of the probable contribution from the remaining ungauged portion of the basin. This assumes that the contribution from the latter was proportional to its area. The contribution measured in different years since 1955, when a gauging weir was installed at Mandini, has varied between 41 % and 29 %. The estimate of total flow during the survey thus is probably conservative, and the actual flow may have been between 5 %, and 20 % greater. The additional water would have come from the lower river catchment.

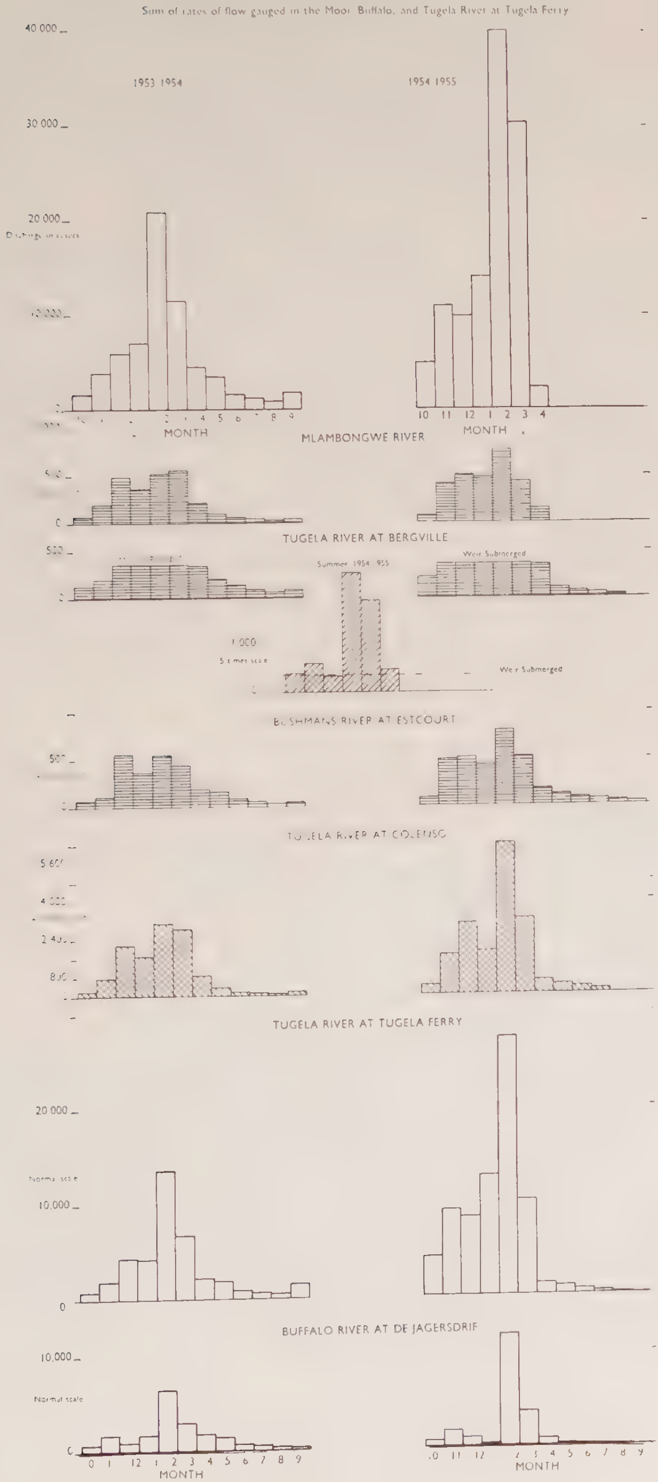
Besides the station at Tugela Ferry, the main river has stations of limited capacity at Bergville and Colenso. In 1955—56, subsequent to the survey, these were rated approximately to measure full flows. In addition, full flow data for Mandini near the mouth were available for this year. Comparison of the discharge at these stations revealed, over the year, that flows at Bergville and Colenso were respectively 15 % and 46 % of the total flow discharging at the mouth.

Using these percentages, the discharges at these stations were computed for the years of the survey.

ii. Annual flows. Rates of flow were high in summer and low in

Figure 4

Distribution of Average Monthly Flows in the Tugela River



winter. The average rate of flow during 1953—54 approximated to the 7 year average between 1946 and 1953. (Table A6 in appendix). The rate during the summer of 1954—55 on the other hand was more than twice as great. This was largely the result of unusally high rainfall in October, November and February. Though the effect of these rains was an immediate increase in flow, they had little influence on flows later in the season. This is illustrated in the histograms in Figure 4.

iii. Sources of Water. The percentage of the seasonal flow which each catchment contributes has been set out in Table A7 in the Appendix.

Examination of this table shows that the eight major tributaries comprising three-quarters of the basin account for slightly more than half the flow in summer, and slightly less in winter. The remainder of the flow is accounted for as follows:

> In the summer most of it comes from the catchments of the Sandspruit, Venterspruit, and Tugela Valley, between Bergville and Colenso.
>
> In the winter, most of it comes from the Klip and middle Tugela catchments between Colenso and Tugela Ferry. This is a little surprising in view of the relatively low rainfall in this area.

3. Description of the main Tugela river.

(a) **Division into Zones.**

It is usually possible to recognise three main regions in a river: a torrential upper river region, a stable middle region, where deposition balances erosion, and a lower region, where the river traverses a flood plain. Straight-forward division of the Tugela river on this basis has not been possible because:

i. there is no recognisable lower region of deposition.
ii. torrential stretches recur in the middle region, between Colenso and Ngobevu.

Both these departures from the ,typical river' result from rejuvenation of the lower reaches through the elevation of the coastal plain: Hard rock strata have been uncovered and rapids formed. Rejuvenation of this nature is not uncommon in large rivers (Hesse 1937).

Other systems of zoning have been suggested. Those of Carpenter (1928) and Butcher (1933), are perhaps best known, but have not been adopted because the fauna and flora on which they are respectively based do not occur in the river. The system adopted has been based on the gradient of the river and the associated fauna, and eight distinct zones have been recognised:

1. The Source zone.
2. The Waterfall zone.
3. The Mountain Torrent zone.
4. The Foothill Torrent zone.
5. The Foothill Sand Bed zone.
6. The Rejuvenated river zone
7. The Valley Sand Bed zone.
8. The Estuarine zone.

(b) **Description of Zones** (see Figure 3).

The upper river — The first four zones, where the river is predominantly a mountain torrent, extend from the source to the vicinity of the Caverns' Causeway, a distance of about 17 miles.

1. The Source zone lies between 10,400 ft. and 10,000 ft. and is about 0.8 miles long. The river rises on top of the basaltic lavas of the Drakensberg escarpment at Mont-aux-Sources, and drains a sponge of rather shallow, black, turf soil, as a small stream, with an average gradient of about 150 ft. to the mile.

2. The Waterfall zone begins where the river plunges 2,500 ft. over the face of the escarpment in a series of waterfalls. This zone covers about 1.5 miles.

3. The Mountain Torrent zone follows below 7,500 ft., where the river flows in a steep-sided gorge, over a series of small falls and rapids at the foot of the mountains, on sandstones of the Stormberg series. It extends about 4.3 miles, and the average gradient over the zone is 186 ft. to the mile. The vegetation of the banks is highland sour veld with krantzes largely covered by forest and scrub-forest. Lower in the zone, the scrub forest thins and the dominant shrub is *Leucosidea sericea*. There is little true emergent aquatic vegetation.

4. The Foothill Torrent zone commences below 5,000 ft. where the valley widens, and the river runs rapidly down a steep boulder bed, in foothills of the Stormberg series. It extends for about 10.5 miles to the vicinity of the Caverns' Causeway at about 4,000 ft. The zone is more stable and occasional pools, sandbanks, and patches of fringing vegetation, usually *Cyperus marginatus* or grasses, e.g. *Hyparrhenia glauca*, *H. hirta*, and *Pennisetum natalense* occur. The average slope of the bed is about 100 ft. to the mile.

The remaining four zones — the Sand Bed zones, extend from Caverns' Causeway to the sea, a distance of 303 miles. Here the river is more stable, the rate of flow is generally reduced as compared the mountain river region, there are considerable areas with a bed of sand or mud, and there is a margin of riverine vegetation. This usually consists of *Cynodon dactylon*, *Cyperus marginatus*, *Hemarthria altissima*, and *Phragmites communis*. Some rapids occur in places.

5. The Foothill Sand Bed zone extends from the Caverns' Causeway above the Oliviershoek road bridge, to Hart's Hill below Colenso — a distance of about 106 miles. The river drops gently to a height of 3,000 ft. at Hart's Hill, with an average gradient of 10 ft. to the mile. It flows over a wide, rather featureless flat valley of tall grassveld and farming lands, in meandering reaches, with a bed of sand and mud. Rapids occur infrequently.

Besides the emergent aquatic vegetation of the river described above as typical of the region, some grasses, including *Cynodon dactylon* and, in slow flowing stretches some patches of *Polygonum setulosum*, and the aquatic plants, *Potamogeton crispa*, *Chara* sp. and *Najas* sp. appear in winter. The zone ends where the river flows over beds of Ecca shales at Colenso.

6. The Rejuvenated river zone, with step-like alternations of Torrential and Sand Bed sections, extends from Hart's Hill some 71 miles to Ngobevu at an elevation of about 1,380 ft. The river traverses hilly, drier and warmer thornveld areas of the younger river valley. The zone is peculiar in that it contains two predominantly Torrential regions of relatively steep gradient, leading into typical Sand Bed regions of gentle gradient. One series of rapids, with an average gradient of about 43 ft. to the mile, occurs at the beginning of the zone below Hart's Hill, and extends about 14 miles to the farm Gannahoek above Nkasini, at an altitude of 1,800 ft. The other, with an average gradient of 27 ft. to the mile, extends 21 miles below Tugela Ferry. In these areas the river flows over extensive rapids in beds of the Beaufort series, while slower, sandy reaches intervene occasionally. Elsewhere in the zone the reverse is true, and long meandering, slow reaches predominate with an average gradient of about 10 ft. per mile.

7. The Valley Sand Bed zone, — a second foothill sand-bed zone below Ngobevu, extends through the broken thornveld of the lower valley and the coastal belt. The river valley is rugged, wide and deep, and the ancient granites and gneisses have been exposed and much moulded by the river. What rapids there are, are short, and become less frequent in the lower reaches. They are composed mainly of boulder beds and rock bottoms without loose stones.

8. The Estuarine zone follows, in country composed largely of rolling hills without great differences in altitude, since there is no lower river, or flood-plain zone, as previously mentioned. The length of the estuary depends upon the rate of flow of the river, and is always short; when the river is in flood it is very short and hardly exists; when the river is low it extends about a half-mile from the mouth.

(c) **Sources of Contamination.**

As contamination can materially alter the normal state of a river, attention was given to all sources found. (See Table A8). At a number of places, mainly on small tributaries, disturbances of the usual fauna and flora were observed. In cases of pollution with organic material, the appearance of ‚sewage fungus' organisms, and disproportionately large numbers of Nematoda, Naididae and Tubificidae were found. In cases of pollution with mineral salts, the usual proportions of plants and animals were upset, and disproportionate numbers of aquatic air-breathing insects, and algae occurred. In extreme cases the fauna was much impoverished and few or no animals could be found.

These polluted tributaries were much diluted on entering the Tugela, and the pollution had little effect on the Tugela river itself. In fact, only at Mandini, late in the survey, was there any real disturbance in the main river. This was only a temporary occurrence, and will be detailed later. The main river therefore can be regarded as virtually unpolluted.

4. GENERAL FEATURES OF THE TRIBUTARIES.

a. The Mlambonjwa and Little Tugela tributaries, which join the Tugela in its upper catchment, are somewhat similar to the main river itself. They rise in the Drakensberg mountains, and follow similar courses through upper river zones, in mountainous country, with a high rainfall. They have short middle river regions, where they flow across the wide Bergville valley before joining the main river.

b. The Bushmans river, which rises at Giant's Castle in the Drakensberg, differs from the Tugela in some respects. Its upper river valley is comparatively narrow and the gradient is not quite so steep, with the consequence that the upper river zones are longer. The Foothill Sand-bed zone continues to Estcourt, and a Rejuvenation zone extends to the junction with the Tugela.

c. The Mooi river, which rises at Giant's Castle, differs in having a very long stretch of Foothill Sand-Bed zone, with gentle gradient downstream as far as Middlerest. The slow flow in this zone results in a fauna and flora differing in a number of respects from those of the Tugela. Below Middlerest the river drops into the Tugela river valley and closely resembles the main river itself.

d. The Klip and Sundays rivers arise in relatively drier areas, and flow by gentle gradients to the main stream. Though having basic resemblances to the Tugela, they are rather unusual on account of their gentle gradients and because they receive mining and industrial effluents.

e. The Buffalo river is the largest and most important tributary of the Tugela. Compared with the Tugela the catchment is relatively dry. Its Foothill Sand-Bed zone stretches roughly as far as Ingogo. Below this, the river falls in rapids to a long Valley Sand-Bed zone of gentle gradient. Finally, below Vant's Drift the river falls more quickly, and a mixed zone of Rejuvenation extends to the junction with the Tugela. It receives some contamination from coal mines.

f. The lower river, below the confluence with the Buffalo, has a number of tributaries such as the Insuzi, Mfongosi, and Inadi, whose sources are in highlands, from which they flow rapidly and sometimes precipitately down to join the Tugela. In general, the zonation observed in the Tugela river is repeated in miniature in these streams, though the relative lengths of the zones are different.

5. METHODS AND LIMITATIONS OF THE SURVEY.

Procedure: — After a preliminary survey of the Tugela river eleven sampling points were chosen along the length of the whole river. These were visited monthly, when simple determinations of temperature, pH, and dionic conductivity were made, „snap" water samples were collected in 600 cc bottles, and quantitative samples of the fauna were collected, and taken to the laboratory for examination.

The pH measurements were made with a portable glass electrode pH meter, conductivities by means of a Dionic water tester, and current speeds with a midget current meter.

Determinations were made of the amounts of dissolved solids; of oxygen absorbed in 4 hours from N/80 potassium permanganate at room temperature; of free and saline ammonia; alkalinity; chlorides; sulphates; calcium and magnesium. Occasional determinations of nitrites, nitrates and phosphates were also made.

Methods of chemical analyses: The methods used were largely those recommended by the SOUTH AFRICAN BUREAU OF STANDARDS in their Specification for Water for Domestic Supplies (1951); calcium and magnesium were determined by the versenate method recommended by the AMERICAN PUBLIC HEALTH ASSOCIATION in Standard Methods for the Analysis of Water (1955); sulphates, by an optical turbidimetric method; nitrites, nitrates, and phosphates, by colorimetric methods recommended by HELLIGE (1947); and free and saline ammonia by a semi-micro distillation method. The amounts of silt were determined by filtering through paper, drying, and weighing.

The accuracy of the analytical methods is indicated in Table 2. The expected precision is within about 5 %. However, when approaching the limit of sensitivity of the tests, errors as large as 25 % or 50 % are possible. This often applies in the present survey to

measurements of nitrogen compounds and oxygen absorbed by permanganate.

Methods of sampling the fauna. — Quantitive samples were taken from the following habitats in the river at each station: —

i. loose stones in rapids,

ii. marginal vegetation,

iii. bed sediments; mud, or mud and sand.

The Surber square foot bottom sampler was used in rocky runs; a hand net of 25 cm. diameter was used to sample a measured length of marginal vegetation; and the Birge-Ekman grab, covering an area of 232 sq. cm. was used on bottom sediments. Net material with 9 meshes per cm., and an opening of approximately 1 mm. was used throughout. The units selected in presenting the results were the numbers of individuals per square foot (929 sq. cm.) in stones in rapids, the numbers per ten foot length (3 metre) of marginal vegetation, and finally, the numbers per $\frac{1}{4}$ square foot (232 sq. cm.) in bottom sediments.

The accuracy of the methods of sampling: Sampling the margins by sweeping a hand-net through a measured length of vegetation is open to a number of errors. These have been reduced by sampling when possible, the trailing grasses at a depth of 25 cm. in one sustained sweep .Though the errors involved in using this standard procedure were no worse than those inherent in sampling by means of the Surber sampler, the method is more subjective, so comparison of results is valid only when the personal error is constant.

All the sampling methods involve the use of nets directly or indirectly and an intrinsic error therefore arises from losses through the mesh openings. For instance, in parallel collections in rapids in the Tugela river with meshes of 9 and 24 meshes per cm., (24 and 58 per inch) the fine meshed net retained twice as many individuals as the coarse net. Macan, (1958) comparing catches of five species of Ephemeroptera, found that a net of 180 threads per inch retained ten times as many individuals as a coarse net of 20 threads to the inch. He demonstrated that large numbers of *Baetis rhodani* (93.8 %) were lost through the coarse net. The conclusion is, therefore, that on account of net losses, the actual numbers in the Tugela river are probably at least twice as great as those recorded. The numbers, therefore, cannot be regarded as an estimate of the actual population but are rather an estimate of the minimum numbers of larger animals in the river.

The population sampled and described is also limited by systematic difficulties as not all the species collected could be named. Unnamed species have been numbered and will be named later. Discre-

pancies may also have arisen from the fact that great variations in river level occasionally made it impossible to sample exactly the same habitats at each station.

Precision: — Table 3 lists percent coefficients of variation for numbers reported by authors who used similar methods in stones in current and it will be seen that these vary between 20 % and 111 %. Table 4 lists the coefficients of variation in total numbers, and in numbers of Ephemeroptera, a group which appear to be uniformly distributed in Natal rivers. The deviations of means expected with different numbers of sub-samples, are expressed as percentages of the mean, and it will be seen that the coefficients of variation lie between 28 % and 65 % and are of much the same order as those reported above.

This large variation is the result of the non-random distribution of the species composing the fauna, (mss. in preparation), and could not be eliminated from the sampling method. The estimates can be improved by increasing the number of samples taken at each point, but the number required for reasonable accuracy is large. In fact, as NEEDHAM & USINGER (1956) have shown that 193 samples are required to estimate the weight of individuals in a 100 sample population with 95 % accuracy, and 73 samples are required to estimate the number of individuals with the same degree of accuracy, it is impractical to aim at a high level of accuracy in a general survey.

The expected deviations indicate that mean numbers based on five sub-samples can be expected to vary by about ± 70 % in the fauna of the rapids, and by ± 40 % in the fauna ot the marginal vegetation, in 95 cases out of 100. Differences between total numbers collected monthly must be greater than ± 70 % and ± 40 % respectively, to be judged significant. Small variations in numbers are of no significance. Thus, in this survey, only large differences such as those between the numbers found in winter and summer are significant, and small differences may be due solely to sampling variations. In considering the fluctuations in numbers of individuals, actual numbers have not been quoted but general levels of abundance have been indicated. Actual numbers have been used in the histograms but must be considered in the light of these variations.

Considering now the representation of species in samples of a fauna, NEEDHAM & USINGER (1956), using methods similar to those employed in rapids in the Tugela, found that 2—3 samples were sufficient to obtain at least one representative of any common group found in 100 samples from a uniform riffle (rapid). They also calculated that between 2 and 12 samples (depending on the rarity of the species) were required to be certain of collecting at least one representative of any particular group. Thus, the methods used in the

survey seem adequate to secure representation of all the common groups and species.

GAUFIN et el. (1956), who used collecting methods comparable to those used in the Tugela, found that of all the species revealed by taking 10 samples, 50—70 % would be present if only three samples were taken, and 70—80 % present if five samples were taken. The application of similar analysis to the data on collections from stones in the rapids in the Tugela yielded the following figures:

40 % of all the species revealed in 9 samples were present in one sub-sample; 65 % were present in 3 sub-samples; and 79 % were present in five sub-samples. Five sub-samples thus yield a reasonable proportion of the fauna of the area sampled.

It, therefore, appears probable that a small number of sub-samples give adequate representation of common species in the fauna of an area.

It is, however, more difficult to discover the relationship between the population as sampled, and the actual fauna of a particular habit, and to do this a number of theoretical assumptions have to be made. A number of authors, WILLIAMS (1939, 1944, 1947, 1953), FISHER, CORBET & WILLIAMS (1943), PRESTON (1948), and GRUNDY (1951), amongst others, have examined the representation of species in samples of a population, with a view to determining the probable numbers of species in the whole population. The most promising concept seems to be that of a log-normal distribution, as suggested by PRESTON (1948), and examined and worked out by GRUNDY (1951), and WILLIAMS (1953).

Assuming that the numbers of individuals per species are log-normally distributed, which the above-mentioned authors have shown to be not unreasonable, calculation indicates that one subsample probably reveals 23 % of the possible species in the population which can be captured by the sampler at a particular point; that three sub-samples reveal 36 % of the population, and that five sub-samples reveal 44 % of the population of any particular habitat in the Tugela. Since three to five sub-samples were taken on each occasion during the survey, it is deduced from these calculations, that about 40 % of the different species actually present were collected. The 60 % missed are species which can be captured only by increasing the number of samples considerably; for instant, 9 samples would yield 56 % of the species; 36 samples would yield 76 %; 72 samples would yield 78 % of the total species in the population, and it would be quite impractical to sample much more than 85 % of the actual species.

The conclusion from the available evidence is, therefore, that the methods used in the survey will have revealed all the common species, and some of the rarer ones as well.

6. CONDITIONS IN THE TUGELA RIVER.

(a) **Physical Conditions.**

Water temperatures: Such data as were available were abstracted from records kept by the NATAL PARKS, GAME AND FISH PRESERVATION BOARD, at National Park and Estcourt, and from records kept by the ELECTRICITY SUPPLY COMMISSION at Colenso Power Station. In addition, occasional readings were taken at Mandini during the course of the survey. The data appear in Tables 5 and A9 (in appendix). Averages have been plotted in Figure 5. (Because there were no records available for the river at Bergville, information about temperatures in the Bushmans at Estcourt were included on the assumption that they were similar).

It will be clear that there was notable variation in the range of temperatures. At the National Park the range was 3.3°C. to 21.1°C. At Estcourt, it was larger, — 1.1°C. to 28.9°C. (some freezing occurred at the margin on cold winter nights), and it is considered that it was even larger at Mandini — certainly the maximum was higher. The river froze over completely in winter only in the source and waterfall zones.

Average temperatures in summer and winter differed by about 10°C. They increased from source to mouth. The average at Colenso was approximately 5°C. higher, and at Mandini was approximately 10°C. higher than that at National Park.

Some idea of the correlation between air and water temperatures can be gathered from the records taken at the National Park. Minimum air and water temperatures were comparable, while maximum water temperatures were about 11°C. lower than the corresponding maximum air temperatures.

Current Speeds. As water velocities are important factors in conditioning hydrobiological habitats, attempts were made to measure them. At each station measurements were made at 4 places; unimpeded flow in deep rapids (deep, strong flows); amongst stones in rapids (stones in current); unimpeded flow in river runs during floods; and at the edge of the marginal vegetation. It will be appreciated that it is difficult to be certain how far these measurements reflect conditions prevailing in the habitats. The results are recorded in Table A10.

Speeds varied considerably at different stations, but no consistent differences between zones could be found.

Unimpeded flows in rapids averaged 79 cm. per sec. in summer and 61 cm. per sec. in winter.

Amongst stones in rapids, speeds varied more, and averaged 39 cm. per sec. in summer and 25 cm. per sec. in winter.

In slow runs speeds varied between 8 cm. and 30 cm. per sec. at most times.

In unimpeded river runs, speeds were much the same as in unimpeded flows in rapids in summer, though speeds of over 152 cm. per sec. occurred during floods, and speeds of 3 to 30 cm. per sec. were usual in winter.

Finally, in the marginal vegetation average speeds were low (3.5 cm. per sec.) in summer, and little movement could be detected in winter.

pH. The results of pH measurements are listed in Table 6 and have been plotted in Figure 5. In both summer and winter there was a clear tendency for values to increase with distance downstream. In the summer the range of values was between 7.3 and 7.8, and in winter was 7.5—8.3. At each station the summer value was always less than that in winter. These trends are consistent with changes which are known to occur in the concentration of bicarbonates.

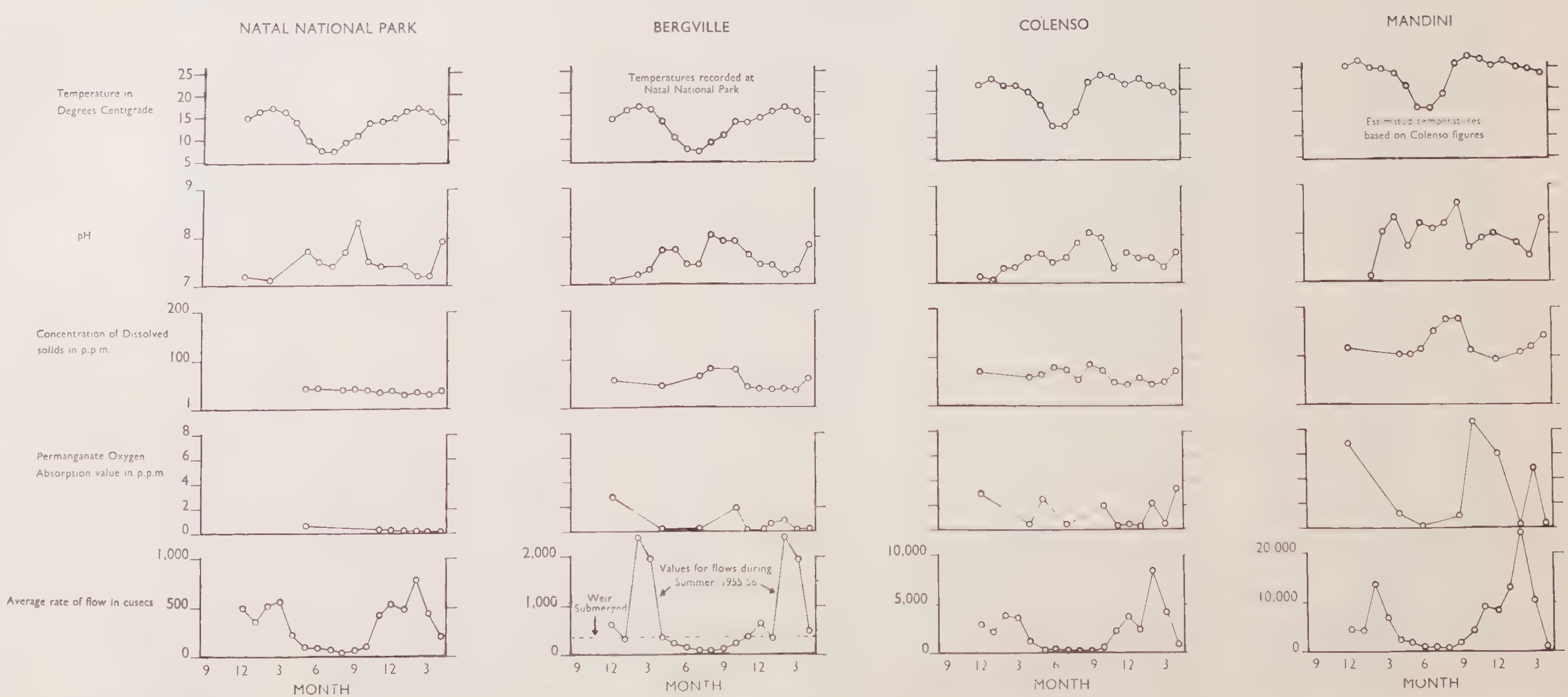
(b) **Chemical Composition** (Tables 6 and 7, and Figure 5).

Analyses show that on the whole the water in the river was of good quality: the concentration of all dissolved solids was never more than 202 ppm.; the dissolved material was mainly the bicarbonates of calcium and magnesium; chlorides and sulphates were present up to 15 and 26 ppm. respectively; nitrogen compounds (as N) and phosphates (as $PO_4{}'''$) hardly ever exceeded 1 ppm.; and no considerable amount of organic matter was present, as judged in terms of the limited tests applied.

Inorganic material. — Levels of dissolved material were consistently matched by the results of measurements of conductivity. At the National Park the values were low in both the wet (32 ppm.) and in the dry season (42 ppm.). Values increased with distance downstream, becoming two or three times as great at Nkasini, about halfway down the river, and three or four times as great at Mandini, near the mouth. In the wet season the concentration of dissolved material was often half that in the dry season, particularly in the lower half of the river. Some rapid fluctuations, within about 10—20 % of the usual value, occurred during floods but normally the seasonal changes were gradual.

Oxidisable organic material. — An assessment of oxidisable organic material was made by applying the test of oxygen absorbed from permanganate (both 3 minute and 4 hour — only the latter appear in Table 5). This measures easily oxidisable material, both organic and inorganic. Under normal conditions no particularly high values were recorded, the highest being 7.4 ppm. oxygen at Ngobevu in the dry

Figure 5 The Physical and Chemical Conditions in the Tugela River between December, 1953 and April 1955



season. During floods in the wet season, however, values of 20—30 ppm. oxygen were occasionally recorded.

Loads of dissolved material. — Table 8 lists the average daily loads of dissolved substances, at selected points in the river and its tributaries, during high and low flow periods. These loads were calculated as the products of average concentrations and volumes, and have been expressed as percentages of the load at Mandini.

The selection of points was limited to places where flow data were available or could be assessed. On the main river these were Colenso,Tugela Ferry and Mandini. The reservations in regard to the accuracy of flow measurements, made in Section 2. g. (Flows) should be borne in mind when interpreting the results.

Examination of these loads throws some light upon the sources of dissolved material in the river and the relationship to geological formations in the basin.

Origin of the loads. — The percentage of the load of dissolved material contributed by each section, together with their percentage flow contribution were as follows:

WET SEASON

Section	% Flow	% Load
Down to Colenso	46	20
Colenso to Tugela Ferry	10	25
Tugela Ferry to Mandini	44	55

DRY SEASON

Section	% Flow	% Load
Down to Colenso	8	4
Colenso to Tugela Ferry	52	79
Tugela Ferry to Mandini	40	17

A notable feature in the wet season is that half the load originated below Tugela Ferry. In spite of its large contribution to the flow the section above Colenso supplied only a small part of the load. This is a feature of waters of the Stormberg lavas and sandstones of the upper Beaufort beds.

In the dry season nearly three-quarters of the load originated in the Colenso — Tugela Ferry Section. As the region is one of low rainfall, overlying lower Beaufort and Natal Ecca beds, this results was not unexpected. What is remarkable, is that nearly half the flow entered the river in this section, most of it (43 %) from catchments which are not gauged at present.

The origin of Constituents of the Loads:

i. Section down to Colenso. — In the wet season a disproportionately high percentage of dissolved solids, (13 %) came from the Venterspruit and Sandspruit streams, and from the river valley below Bergville. One half of this load consisted of sodium salts (estimated by difference), and the section provided half the sodium salts in the whole river.

The characteristics of the water in this section are consistent with the known features in ground waters found in the Stormberg lavas and sandstones of the upper Beaufort beds (Table A11, in appendix), which, Bond (1946) has shown, provide ground water low in dissolved solids consisting largely of calcium, magnesium, bicarbonates, some sodium salts and little sulphates and chlorides.

ii. Colenso to Tugela Ferry. — Most of the material (17 % of the total load in the wet season, and 68 % in the dry season) came from the Klip river catchment and the mid-valley areas around and between Nkasini and Tugela Ferry which comprise 12 % of the basin. Rather more calcium and magnesium salts and sulphates were present, while little sodium accrued in the section. About three-quarters of the load of sulphates, chlorides and bicarbonates in the river in the dry season came from the section.

The proportion of materials entering the river water in the section bears resemblance to that in the ground waters of Lower Beaufort and Northern Natal Ecca beds which underlie its catchment.

The geological formations thus appear to have an important formative influence on the composition of the water in the region, both in summer and winter. Where catchments lie over mid- and upper-Beaufort beds, as does that of the Blaauwkrantz river, some increases in sodium salts are found.

Study of tributaries entering this section of the river confirms the above findings. For instance, the concentration of dissolved solids was high in the Blaauwkrantz river (595 ppm.) and consisted of calcium and magnesium bicarbonates, some chlorides, sulphates, and sodium (estimated by difference). It received overflow from the Weenen irrigation settlement, but this was not the main source of the material.

A study of data from the Mooi river affords another example. Comparison of the loads at its gauging stations in middle and lower reaches, shows that the load of dissolved solids originating in the lower river both summer and winter, was much greater than that coming from the upper river. The load in summer in fact was 4.6 times, and in winter 2.9 times as great as that in the upper river, although the flow per square mile of catchment in each area was much the same. (The flow per square mile was actually a little greater in the lower river than in the upper in summer, and somewhat less in the winter (60 %)). Thus, most of the dissolved material from

this particular catchment must have arisen in the eroded and broken thornveld of the lower river valley, both in the wet and dry seasons.

It appears that the catchments of the Colenso-Tugela Ferry section contribute comparatively large loads of dissolved material, particularly in winter.

iii. The Tugela Ferry-Mandini section. — The greatest proportion of material accruing in this section (35 % in the wet season and 29 % in the dry season) came from the Mooi and Buffalo rivers, and of these, the Buffalo was by far the more important, as it alone supplied about a third of the total load in the wet and dry seasons. The remainder came from the lower river valley.

It is noteworthy that most of the sulphates in the river in the wet season originated in this section (79 %). Most (42 %) came from tributaries, though a considerable amount (37 %) also came from the lower river catchment. It is possible that the load of sulphates in the river is influenced by coal mining activities in Northern Natal, particularly as the contribution came mostly from the tributaries in the dry season. The load in the lower river may have come partly from the doleritic intrusions and Ecca beds of the Natal coast. Most of the chlorides in the river (57 %) in the wet season also came from this section.

The estimates of the dry season loads in Table 7 show some discrepancies which probably arise from inaccurate flow data. (It seems that the flow originating in the lower part of the Buffalo river catchment was probably less than that estimated in proportion to its area). Nevertheless, it seems clear that relatively large amounts of chlorides, sulphates, and sodium salts, came from the Buffalo and Mooi rivers both in the wet and dry seasons, and that large amounts of sulphates came from the lower river catchments in addition in the wet season.

These features are to be expected in waters of the Ecca and upper Beaufort beds, and are probable in waters of the Ecca beds in the catchment of the lower river. The slight drop in concentration towards the mouth and the preponderance of magnesium over calcium salts, are expected, for BOND (1946) has shown both, that waters of the Dwyka beds, Old Granite, and Table Mountain sandstones, contain less dissolved solids than those found in the Ecca beds, and that they contain higher percentages of magnesium salts.

(c) **Silt.**

i. Concentrations of suspended silt. — The concentration of suspended silt proved to be the most variable single feature of the composition of the river water. Little or none was present in the dry season, whereas a high but variable amount was carried during the wet season.

The average annual percentage during the years 1955—56 and 1957—58 was 0.23 % dry weight, but the actual concentration varied greatly from day to day, and even from hour to hour when the river was in spate.

For instance, the concentration varied between 0.02 % and 2.78 % by weight at Bergville on two consecutive days. (The value 2.78 % was the highest recorded during the survey). The variability is also illustrated by the monthly averages in Tables 9 and 10.

ii. The Origin of silt loads. — Consideration of the figures for the tons of silt coming from each square mile of the catchments, and of the loads and percentage contributions of the sections, throws some light on the soil erosion which has taken place. (Table 11). It is noteworthy that more than three-quaters of the load was contributed by the section between Colenso and Mandini, from the broken, more eroded, dry thornveld areas. It is also striking that the load per square mile between Bergville and Colenso was more than twice that in the whole catchment, and it appears that the tall grassveld, and farmed lands of the section, have contributed large amounts of silt, probably from easily eroded sub-soils.

iii. The distribution of the loads. — Scrutiny of the very variable daily silt loads (ms. in preparation) reveals that the greatest proportion of the annual load was transported by the river on a few days during summer. For instance, 51 % of the total annual load at Bergville passed the station on two non-consecutive days in February. Further downstream the peak loads became smoothed, and in two days in February, 36 % of the total load passed Colenso, and 28 % passed Mandini. Such variations in the loads are, of course, expected as the silt must arise when rains fall of sufficient intensity to cause much surface water to wash into the streams and rivers of the catchment. Such rains and storms in summer often occur in different parts of the catchment at different times. A detailed account of the silt loads will be given in a later publication.

Variations in the rates of flow, and silt loads naturally have a potent effect on the fauna and flora of the river: when the velocity of flow is high, silt is retained in suspension, and abrasion, scouring, and the opacity of the water impose severe conditions upon the inhabitants in the river: on the other hand, when the flow slackens, silt is deposited, and creates an environment which is unsuitable for some species.

7. THE FLORA OF THE RIVER.

In common with many other swift rivers in Africa, the Tugela has a relatively poor flora. This is probably due to a number of factors, including the very great extremes in the rate of flow, the

heavy load of silt in the wet season, and the fluctuations of the water level. It is difficult to decide exactly what is the margin of the river, as the changing level alternately immerses and exposes emergent aquatic vegetation, and bank species, normally grasses. As a result, very few true aquatic plants become established and only a few hardy species of emergent plants such as *Phragmites communis* and *Cyperus marginatus* are found lining the banks.

A list of common species of plants on the river banks and in the marginal vegetation, with author names, is given in the appendix (Table A12) and only the more important features of the flora will be considered below.

Conditions in the river become suitable for a growth of algae and diatoms only in the dry season when the rate of flow drops, the level steadies, the turbidity of the water decreases, and the concentration of nutrients increases. The microflora is thus peculiarly seasonal and hardly ever becomes a considerable factor in the biology of the river. In late winter, however, a growth of filamentous algae and diatoms occurs, particularly in the Sand Bed zones, sufficient to influence the fauna in the marginal vegetation. This was a noticeable occurrence at Tugela Ferry in October. The details of the algal and diatom flora of the river have been recorded in separate publications by Dr. B. J. CHOLNOKY (1956, 1957 and another in preparation).

The vegetation in the zones of the river.

In the source zone (Mount-aux-Sources) the stream is fringed by stream-bank grasses which sometimes trail in the water. Some mosses grow in the bed, particularly on steep faces in rapids or falls.

In the Mountain Torrent zone below the falls, (National Park) there is little true emergent aquatic vegetation as the banks are precipitous and rocky. The grasses and annuals on the banks sometimes trail in the water and form a fringe, but no submerged aquatic vegetation occurs.

In the Foothill Torrent zone (Lower National Park and Caverns' Causeway) the river is more stable and occasional pools, sandbanks, and patches of marginal vegetation are present. The vegetation is composed usually of *Cyperus marginatus*, *Pennisetum natalense* and *Ornithogalum zeyheri* where the water is flowing rapidly, and grasses such as *Hyperhaenia glauca*, *H. Hirta*, and occasional patches of *Phragmites communis*, where the flow is slower.

The predominant characteristics of the lower Sand Bed zones (Oliviershoek Bridge to the mouth) are their greater stability and the presence of a more or less complete fringe of river bank vegetation, which usually consists of *Cynodon dactylon*, *Cyperus marginatus*, *Hemarthria altissima*, *Phalasis* sp. and *Phragmites communis*. In slow-flowing stretches some patches of the aquatic plants,

Potamogeton crispa, *Polygonium setulosum*, *Chara* sp. and *Najas* sp., and algae, largely *Spirogyra* spp., appear in the winter months.

8. THE FAUNA OF THE RIVER.

The density of individuals of all species collected at each point will be considered before examining the main features of the composition of the fauna of the various zones in the river. Table A14 (in appendix) shows the numbers of individuals collected.

Population density in the rapids: The greatest density of animals was found in the headwaters of the upper river (average numbers over the whole year being 160 per square feet). The next greatest, (97 per sq. ft.) occurred in the torrential areas of the middle river at Nkasini and Tugela Ferry. These were particularly high in July, August and September and doubtless were related to the growth of algae which was mentioned in the previous section. Elsewhere average numbers were about 80 per sq. ft.

Population density in the marginal vegetation: Highest average numbers, 130 per 10 ft. of marginal vegetation, were collected from the marginal vegetation in the upper river, and Foothill Sand-Bed zones. Average numbers were 105 in the rest of the river except at Nkasini and Middledrift, where 70 and 80 respectively, were obtained. No explanation for the lower numbers at the last two named stations can be offered.

Population density in the bottom sediments: At the three stations where bottom sediments were examined, average numbers over the year were found to increase downstream by about 80 per sq. ft. at each station, rising from 72 per sq. ft. at Bergville to 256 per sq. ft. at the lower station at Mandini. This increase in density was presumably a result of a similar progressive increase in nutritive value of the muddier bottom sediments.

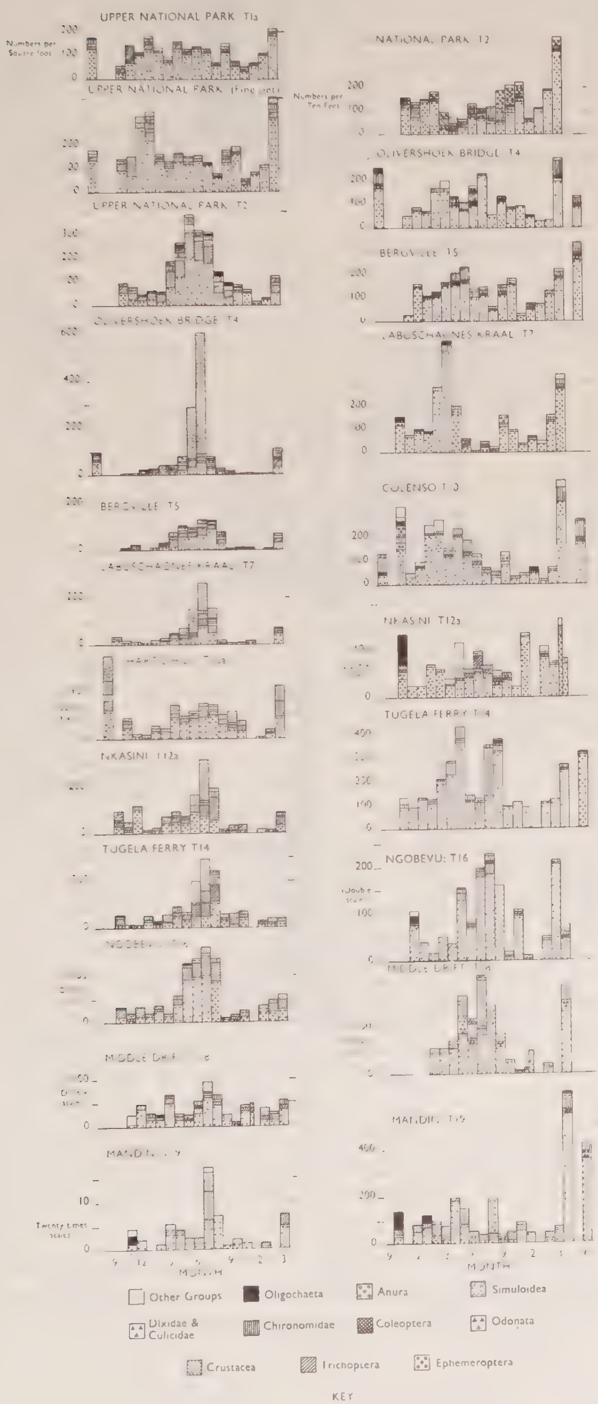
The distribution of the fauna:

Presentation of the results: — The distribution of the commoner representative species in the fauna of each of the three main habitats, stones in rapids, marginal vegetation, and bottom sediments is given in Table 12. Species were designated „of significance" if they were represented more than four times in the possible 163 collections made during the whole survey of the river.

The seasonal distributions of the main groups in the fauna are represented in Figures 6 and 7 where the numbers of individuals in different orders, and sometimes families at each station, are represented by histograms. This very broad grouping serves to indicate the main changes in the fauna. In greater detail the seasonal distributions of each numerically important species in the fauna of each station, have been shown in the form of histograms in Figures 8, 9 and 10.

Figure 6
The Numbers of Individuals in various Groups collected monthly at each Station

A. The Fauna of the Rapids B. The Fauna of the Marginal Vegetation



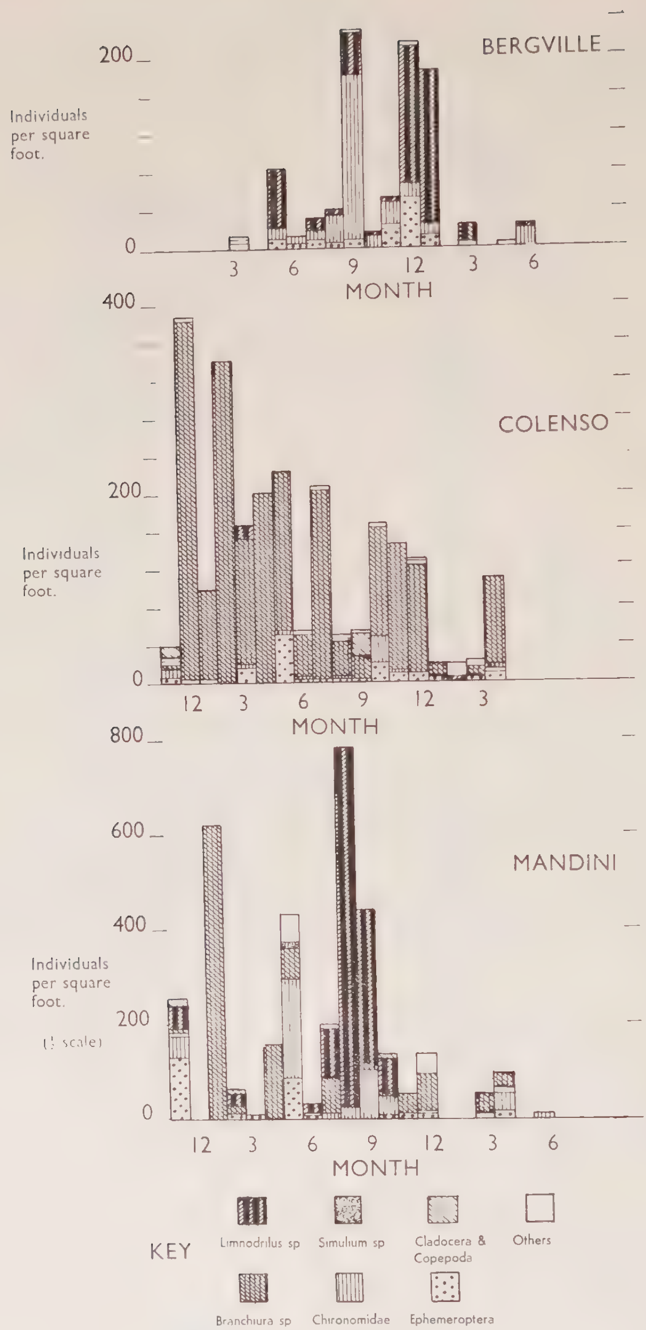


Figure 7
The numbers of individuals per unit collected monthly at each station; classified by taxonomic groups - (c) Fauna of the bottom sediments.

Species have only been included in the figures if their frequency of occurrence in any one collection exceeded 4 per square foot in the rapids, 4 per ten foot length in marginal vegetation, and 16 per square foot in bottom sediments.

Examination of the tables and figures reveals that a few species formed the major part of the fauna of the river, and their numerical relations and zonation set the patterns in the three main habitats in the river which are described below.

(a) **The inhabitants of the stony bottom in rapids.**

The numbers of individuals were generally low in the wet summer season, and high in dry winter season except in the upper river region. This trend was as true for most individual species composing the fauna as it was for total numbers, for only three species, *Neoperla spio*, *Elassoneuria trimeniana*, and *Neurocaenis discolor*, were more numerous in summer than in winter.

1. The upper river zones.

The species composition of the fauna of the upper river differed greatly from that of the remainder of the river. Many species were found only in this region. In addition, the density of the fauna was comparatively high, and variations did not follow the seasonal pattern found elsewhere. Further, the species composition of the zones of this region differed sharply amongst themselves, despite the fact the zones are short. The main characteristics of the fauna of the zones were as follows: —

The Source zone: — The community is known from three collections made at different seasons, and appears restricted. The population was dominated by *Simulium nigritarsus* and *S. unicornutum* in February, while in June, the Mayflies *Adenophlebia auriculata* and *Centroptilum sudafricanum* became prominent, and in November, *Adenophlebia auriculata* and the midge, *Tanytarsus* sp. 1 were most numerous. These, together with lesser numbers of *Acentrella natalensis*, *Pentaneura* sp. 1., were the main constituent species of the fauna. In addition, the isopod *Crangonyx robertsii*, and the frog, *Rana umbraculata*, through never numerous, were highly characteristic members of the community.

The Mountain Torrent zone: — The population of this zone fluctuated about a comparatively high level thoughout the year, with peak numbers occurring every two or three months. These peaks resulted from increases in numbers of certain species. In spring, *Centroptilum sudafricanum* and *Afronurus harrisoni* were the most important species numerically. In summer, other species, namely *Baetis harrisoni*, *Acentrella natalensis*, *Centroptilum sudafricanum*

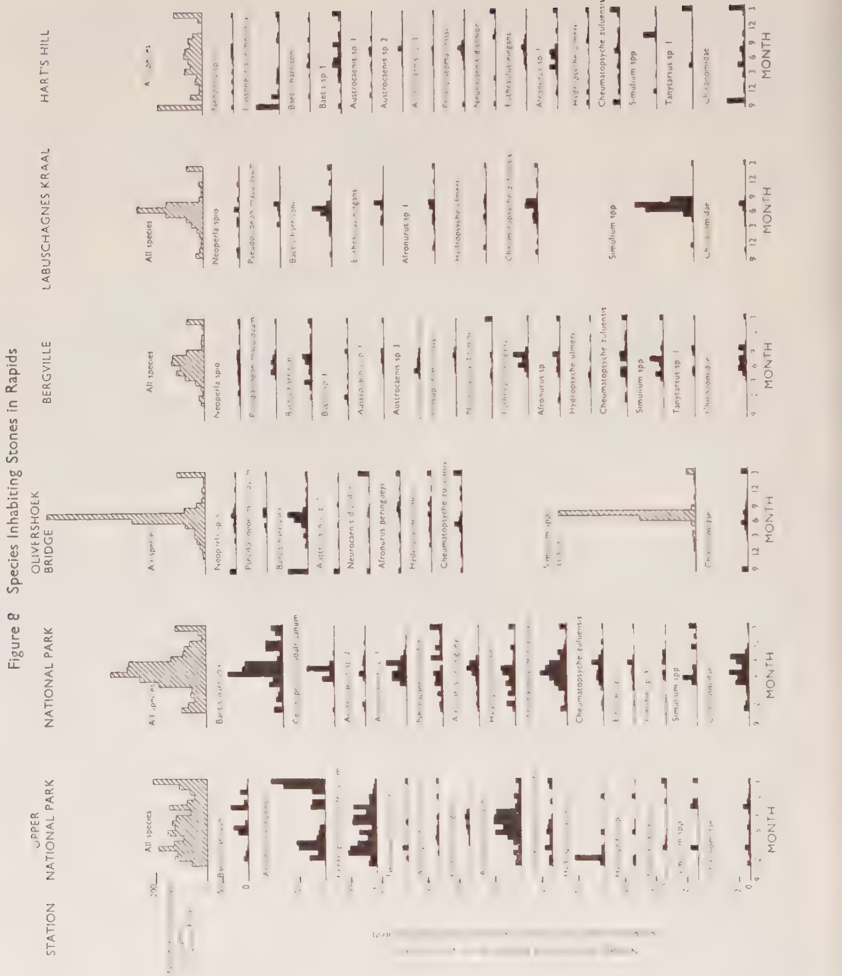


Figure 8a
The numbers of individuals of the common species composing the fauna of the rapids at each station.

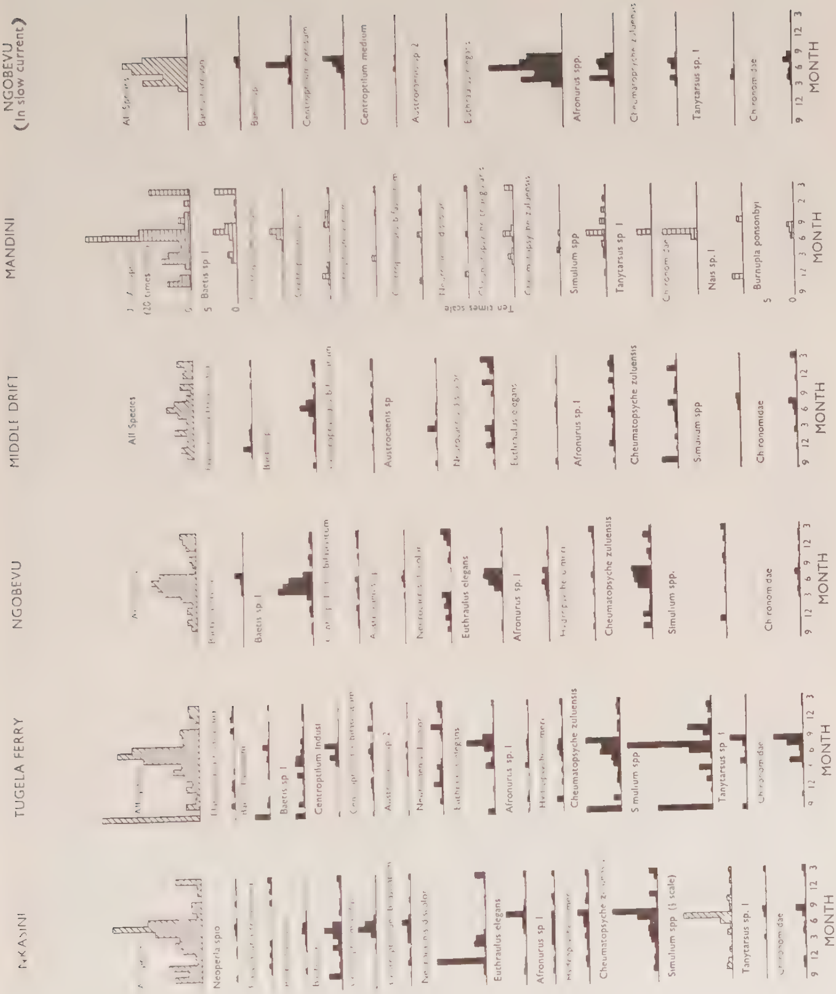

NKASINI
TUGELA FERRY
NGOBEVU
MIDDLE DRIFT
MANDINI
NGOBEVU (In slow current)
Ten times scale
MONTH
MONTH
MONTH
MONTH
MONTH
MONTH

Fig. 8b.

and some Chironomidae dominated the fauna. In autumn, *Acentrella natalensis*, *Centroptilum sudafricanum*, *Hydroptila capensis* and Chironomidae predominated, while in winter, a further new combination of species namely, *Baetis harrisoni*, *Centroptilum sudafricanum* and *Afronurus harrisoni* became dominant. Furthermore, *Protojanira perbrincki*, *Aphanicercella* sp., *Baetis cataractae*, *Aprionyx tricuspidatus*, *Adenophlebia sylvatica*, *Scirtes* sp., and *Rana umbraculata*, though never numerous were highly characteristic components of the community restricted to the zone.

The Foothill Torrent zone: — The population level in this zone, in contrast to the previous zone, was highest in the winter months. The numercially important species in winter were *Baetis harrisoni*, *Centroptilum sudafricanum*, *Caenis* sp. 3, *Afronurus peringueyi*, *Neurocaenis discolor*, *Hydropsyche ulmeri*, *Cheumatopsyche maculata*, *C. zuluensis*[1], Elmidae larvae, *Simulium* spp., and Chironomidae. Most of these species did not occur at all, or were insignificant, in the fauna of the Upper Torrential zone.

In Spring the fauna was much the same, but Chironomidae were relatively more numerous, and in summer, two species, *Baetis harrisoni* and *Neurocaenis discolor* (a species which did not figure in the previous zone) dominated the fauna. *Acentrella natalensis* and *Centroptilum sudafricanum*, so common in the zone above, were absent.

2. The Rapids in the Sand Bed zones.

The fauna of the remainder of the river was almost entirely different from that of the upper river. It was composed mainly of a few species which were more or less common throughout its length. The density of the fauna followed a fairly uniform pattern with an annual increase in numbers in late winter, reaching a peak in August, followed by a decline and uniformly low numbers in the wet summer season.

Four species which occurred throughout all zones in slow currents were *Baetis* sp. 1., *Centroptilum excisum*, *Euthraulus elegans* and *Afronurus* sp. 1. Two other species which were widely distributed in stones in swifter currents, were the Caddis-fly, *Cheumatopsyche zuluensis* and the blackflies, *Simulium* spp.

Although the zones were generally similar, some species were restricted to particular zones. For instance, the important species in rapids in the Foothill Sand-Bed zone were *Neoperla spio*, *Pseudocloeon maculosum*, *Baetis harrisoni*, *Caenis* sp. 3, *Euthraulus elegans*,

[1]) The larvae of species of the genus *Cheumatopsyche* proved difficult to separate, and some closely related, though comparatively rare forms, may have been confused with each of these two species.

Afronurus sp. 1, *Af. peringueyi*, *Hydropsyche ulmeri*, *Cheumatopsyche zuluensis*, *Simulium* spp. and Chironomidae. The Tricorythid — mayfly, *Neurocaenis discolor* was not well represented here. Of these *Baetis harrisoni* and *Afronurus peringueyi* were present also in the upper river, and *Euthraulus elegans*, *Cheumatopsyche zuluensis* and *Silimium* spp. were common to all reaches of the section.

Species of importance in the Rejuvenated River zone were *Elassoneuria trimeniana*, *Baetis* sp. 1, *Centroptilum indusii*, *Euthraulus elegans*, *Afronurus* sp. 1, *Neurocaenis discolor*, *Hydropsyche ulmeri*, *Cheumatopsyche zuluensis*, *Simulium* spp. and Chironomidae. Four of these, *Elassoneuria trimeniana*, *Baetis* sp. 1, *Neurocaenis discolor*, and *Cheumatopsyche zuluensis*, occurred in all the lower zones of the river.

In the rapids of the Valley Sand Bed zone the species found to be of importance were *Elassoneuria trimeniana*, *Baetis* sp. 1, *Centroptilum* sp. 1, *C. indusii*, *Caenis* sp. 1, *Neurocaenis discolor*, *Euthraulus elegans*, *Afronurus* sp. 1., *Cheumatopsyche zuluensis*, *C. triangularis* and some *Simulium* spp. Four of these, as indicated above, were common in the previous zone, whereas two, *Centroptilum* sp. 1 and *Cheumatopsyche triangularis* were peculiar to the zone.

These faunae characterised the various zones of the river.

Rocks in slow current in the Valley Sand Bed zone at Ngobevu: — When the river level dropped in the winter months, it receded from the marginal vegetation, and exposed a bed of stones and boulders at this station. This type of habitat, composed of stones in slow flowing reaches, occurred at a number of places in the Sand Bed zones, but was not often seen during the survey, as it usually occurred in deep water.

The species inhabiting the niche were much the same in the different zones, and were similar to those inhabiting the rapids. *Euthraulus elegans*, however, was dominant at all times.

The numbers increased from low numbers in April to large numbers in August. The species *Euthraulus elegans* was accompanied by *Afronurus* sp. 1, *Cheumatopsyche zuluensis*, and some Chironomidae during May, and by the co-dominants, *Afronurus* sp. 1, *Baetis* sp. 1, *Centroptilum excisum*, and lesser numbers of *Baetis harrisoni*, *Cheumatopsyche zuluensis* and Chironomidae in August.

The above description has outlined the main characteristics of the fauna of the zones. There are finally, certain resemblances between the faunae of stations in different zones which are of interest —

i. The stations at Upper National Park, Hart's Hill and Middledrift seem to have stable populations, where the faunae, predominantly mayflies, are dense both summer and winter. The habitats at these stations are more torrential.

ii. The faunae of stations at National Park and Bergville are similar in having high populations in winter months and very low numbers in summer. Habitats at these stations are torrential but tend to some stability.

iii. The faunal stations at Oliviershoek Bridge, Labuschagne's Kraal, Nkasini, Tugela Ferry and Mandini are similar and constitute the common types for the river as described above. They differ from those of National Park and Bergville in having considerable numbers of *Simulium* spp. dominant in winter.

iv. The station at Ngobevu appears to be unusual as caddis-flies (*Cheumatopsyche* spp.) assume importance in winter, perhaps in response to an increase in the amount of suspended food material. Mayflies, however, are predominant at all times, as at other stations.

(b) **The inhabitants of the marginal vegetation.**

The densities of species in the marginal vegetation varied greatly. Numbers generally were high in spring, they dropped in mid-summer, possibly as a result of floods, and then rose to a peak in April in the autumn.

The species of numerical importance were few and were more or less the same throughout the river. They comprised: *Pseudocloeon vinosum*, *Baetis bellus*, *Baetis* sp. 2., *Centroptilum excisum*, Chironomidae, and *Bufo* sp. These constituted by far the largest part of the fauna and changes in their relative numbers set the general pattern of population changes at all stations. (Four stations at the extremities of the river did not entirely conform to the pattern. They represent only one-tenth of the length of the river, however, and will be described later).

The species *Baetis bellus* increased in numbers throughout summer (between October and March), and then disappeared suddenly and completely. *Baetis* sp. 2. appeared later (in February) in the upper and Foothill Sand-Bed zones, and increased in numbers until June, whereafter it entirely disappeared. *Pseudocloeon vinosum* and some species of Chironomidae began to increase in numbers in May, and were numerous in winter (July and August). Fluctuations in numbers of these species resulted in a dense winter fauna, when increases in numbers of *Pseudocloeon vinosum* and Chironomidae offset the disappearance in winter of *Baetis* sp. 2. (Oliviershoek and Middledrift). On the other hand, the winter fauna was comparatively sparse when increases of these species occurred late, or were small (Bergville, Labuschagne's Kraal, Colenso, and Tugela Ferry).

The density of the spring fauna was influenced particularly by the appearance of *Bufo* sp. tadpoles. These appeared in October and November in the Foothill Torrent zone, and in August and September in the Valley Sand Bed zone.

A few other species occasionally influenced the numbers of the total population, but did not alter the general pattern in the river. These were *Baetis* sp. 1. which appeared in August at Middledrift (possibly as the sampling point was near rapids); *Centroptilum excisum*, which appeared in October at Colenso and Tugela Ferry, when a considerable growth of algae was noticed; *Austrocaenis capensis*, which appeared in numbers in May and October at Bergville and Nkasini; *Pseudagrion salisburyense*, which appeared in numbers in winter at Bergville and Middledrift, though some were present throughout the year at most stations; and *Berosus* sp. 1. which appeared in numbers in autumn at Labuschagne's Kraal and Nkasini.

The above were the main characteristics of the fauna of the marginal vegetation of most of the river. As mentioned, some parts of the river, having marginal vegetation, had faunae which did not conform to the general pattern. These will now be described:

The Source zone: — The fauna of the marginal vegetation at Mont-aux-Sources consisted of many species not represented elsewhere in the river. In spring, it was composed largely of the species *Adenophlebia auriculata*, Elmidae, sp. 5., and Chironomidae with lesser numbers of Hydraenidae sp. 2 and *Pentaneura* sp. In summer it was dominated by *Baetis lawrencei*, though some *Pseudocloeon vinosum*, *Simũlium nigritarsis*, *S.* cf. *unicornutum*, *Pentaneura* sp. and Chironomidae spp. were also represented. In winter, in contrast, it was dominated by *Centroptilum sudafricanum*, though *Adenophlebia auriculata*, *Austrocaenis capensis*, *Simulium medusaeforme*, *Limnodrilus* sp. 1 and *Rana umbraculata* were represented. Many of these species, e.g. *Baetis lawrencei*, *Rana umbraculata*, *Simulium nigritarsus*, Elmidae sp. 5. and Hydraendiae sp. 2, were restricted to the zone. Some, e.g. *Adelopnebia auriculata*, *Centroptilum sudafricanum* and Chironomidae sp. were peculiar to the upper river. The other few species were found throughout the river.

The Foothill Torrent zone: — A dense fauna consisting mostly of three species, *Pseudocloeon vinosum*, *Baetis bellus* and *Baetis* sp. 2. occurred in this zone in summer, in autumn, and in winter. An unusual feature, however, was the appearance of numbers of *Baetis harrisoni* in July and December. In addition, the fauna was unusually rich in species of numerical importance, and *Centroptilum excisum*, *Centroptilum sudafricanum*, *Pseudagrion salisburyense*, *Rhagovelia nigricans*, *Microvelia major*, *Dixa* sp. 1. and Chronomidae, all were represented. This was possibly a result of relatively high current speeds in the marginal vegetation (cf. HARRISON & ELSWORTH (1958)). In October and November, frogs and tadpoles suddenly assumed a subdominant position, and then disappeared.

Mandini: — At Mandini, in the lower part of the Valley Sand-Bed

Figure 9 Species Inhabiting the Marginal Vegetation

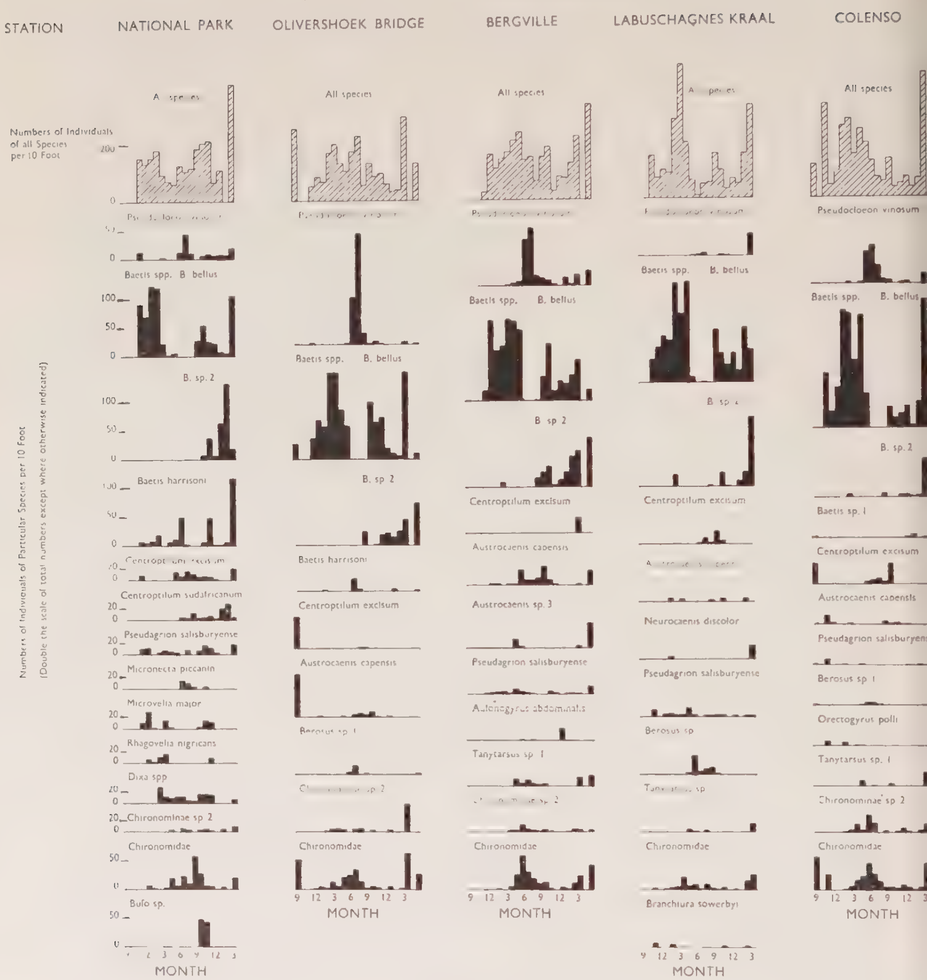


Figure 9a.
The numbers of individuals of the common species composing the fauna of the marginal vegetation at each station.


NKASINI
TUGELA FERRY
NGOBEVU
MIDDLE DRIFT
MANDINI
All species
Sampling commenced
Pseudocloeon vinosum
Baetis spp
B. bellus
B sp 2
Baetis sp 1
Centroptilum excisum
Austrocaenis capensis
Austrocaenis sp
Cheumatopsyche zuluensis
Notonurus cooperi
Orthocladinae sp 3
Simulium spp
Pseudagrion salisburyense
Tanytarsus sp 1
Pentaneura sp 1
Orthocladinae sp 1
Orthocladinae sp 6
Chironomidae
Centroptilum medium
Chironominae sp 2
Simocephalus vetuloides
Caridina nilotica
Macrobrachium equidens
Bufo sp
Branchiura sowerbyi
MONTH

Fig. 9b.

zone, the fauna typical for the zone was present, but in somewhat reduced numbers, and a characteristic feature was a high proportion of the prawns; *Caridina nilotica*, *Macrobrachium equidens* and *M.* cf. *idae*.

The presence of *C. nilotica* may be attributed partly to the reduced violence of flood conditions at this point, where the wide bed is broken by small islands, and partly to the presence of dense margins of trailing grasses (*Cynodon* sp.), for the species is found elsewhere in tributaries where flows are moderate and marginal vegetation is abundant. The presence of *Macrobrachium* spp. however probably depends more upon the higher temperatures prevailing at the coast, and upon proximity to the sea. (cf. the distribution given in BARNARD (1950)).

Population increases in the fauna at the station were observed in January, April, August and November, 1954. In the following year tremendous increases in numbers were observed in April and June. The January increase was due largely to numbers of *Baetis* sp., probably *bellus*, together with *Tubifex* sp. and *Cardina nilotica*. The increase in April was almost solely due to numbers of *Baetis* sp. though some *Caridina nilotica* were also present. The increase in August resulted from the sudden appearance of *Bufo* sp. tadpoles, and that in November resulted from an increase of *Baetis bellus* and *Caridina nilotica*.

This sequence of events, somewhat resembling that in the rest of the river, is probably normal for the population. However, a new factor appeared in March, April and June, 1955 when waste from a Kraft paper mill in the area entered the river above the sampling station. The quantity of waste entering was variable, but at times considerable, and the subsequent events in the river were remarkable.

In March, 1955, *Baetis bellus* and Chironomidae sp. dominated the fauna. Then in April a sudden outburst in numbers of *Baetis* sp. 2 occurred, when 461 per ten foot of marginal vegetation were recorded, accompanied by some *Pseudocloeon vinosum* and Chironomidae. This caused the total population at the station to soar to a maximum value of 627 individuals per ten foot of marginal vegetation, which was about twice as many as ever were found in the river. Two months later, in June, the numbers were still extremely high, with 402 per ten foot of marginal vegetation, but were then largely due to another species, *Centroptilum medium*, which increased to 249 per ten feet of marginal vegetation. In fact, this was the only record of *Centroptilum medium* ever appearing in numbers in the river, as they were usually found only in small numbers under stones in slow flowing rapids or runs. A few other species, *Baetis bellus*, *Centroptilum excisum*, *Pseudagrion salisburyense*, and Chironomidae sp. were also present but not in large numbers.

This unusual increase in numbers in late autumn, when the river was falling, and a simultaneous increase in the amount of algae, probably both resulted from the supply of nutrients in the factory waste. Some increase in numbers in April, 1955, was noticed at all stations on the river, and was possibly an after-effect of the unusual floods of the summer period, but the magnitude of the increase at Mandini was unique, and clearly indicates the effect of the contamination of the river.

The Estuarine zone: — The fauna of the estuary naturally differed from that in the rest of the river. Too few collections were made to type it accurately, but it appears to have varied between a freshwater and an estuarine type depending on the season.

During high flows, the level of the river was generally so high that the salinity of the water was negligible. The fauna was correspondingly poor in numbers and consisted mainly of members of the usual fauna of the marginal vegetation of the Valley Sand-Bed zone; *Baetis bellus*, *Baetis* sp. 2., *Cardina nilotica* and *Macrobrachium idae.*

In the autumn (March), when the river level dropped after the summer floods, estuarine conditions became established and numbers of *Palaemon pacificus* were collected, accompanied by some *Gastrosaccus brevifissura*. In April, the fauna consisted mainly of *Pontogeloides latipes*, *Sesarma catenata*, *Macrobrachium idae* and *Caridina nilotica*, and in the dry season between June and September, there were in addition the species, *Sesarma eulimene*, *Penaeus monodon*, *Palaemon pacificus* and cf. *Assiminea* sp.

(c) **The inhabitants of the Bottom Sediments.**

There were three main types of sediments in the river. Above Bergville in the Foothill Sand-Bed zone they were mainly sand. In the remainder of the river in the Sand-Bed zones, they were largely sand with a little mud. Occasionally in deep pools, they were composed mainly of mud.

The first of these types was sampled at Bergville, the second at Mandini and the third at Colenso. These different conditions doubtless influenced the populations of the stations, and *Limnodrilus* sp. 1 and various species of Chironomidae and Ceratopogonidae appeared to prefer the light sandy type of bed, while *Branchiura* cf. *sowerbyi* was restricted to soft deep muds.

The patterns of numbers were quite different at the three stations and depended upon different component species in each case. In the sandy bottom at Bergville *Procladius* spp. 1 and 2, *Tanytarsus* sp. and other Chirominodae were important in July. These were superseded in October by *Limnodrilus* sp. 1 and Chironomidae sp.

Figure 10 Species Inhabiting the Bottom Sediments

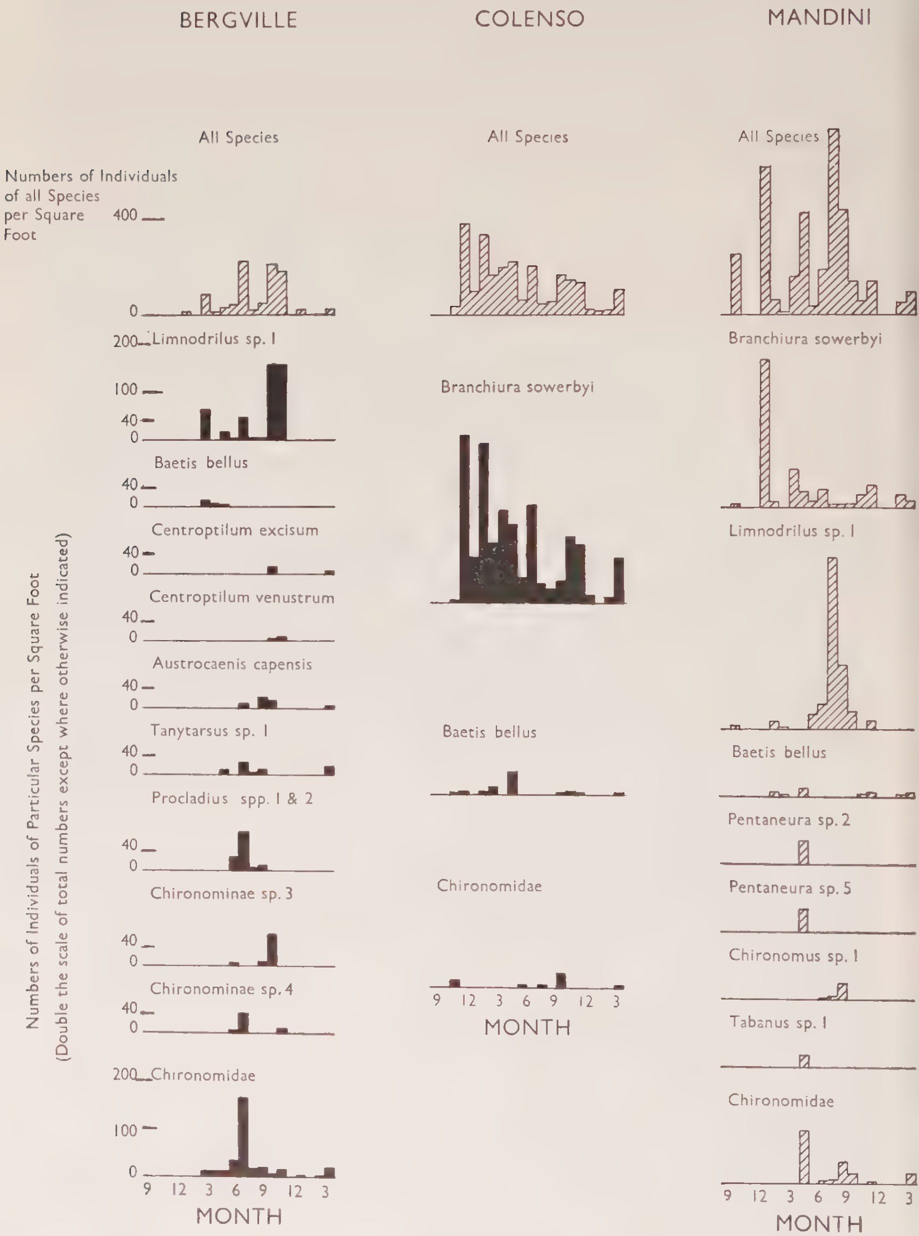


Figure 10
The numbers of individuals of the common species composing the fauna of the bottom sediments at three stations.

accompanied by lesser numbers of *Centroptilum excisum*, *C. venustrum* and *Austrocaenis capensis*?

The inhabitants of the sediments of the predominantly sandy beds in the remainder of the river below Bergville, as determined in supplementary collections, were generally the same throughout the river. The fauna was composed of: *Limnodrilus* sp. 1, *Branchiura* cf. *sowerbyi*, *Centroptilum excisum*, *Baetis bellus*, *Paragomphus cognatus* or *P. hageni*, Chironomidae, including *Procladius* spp. 1 and 2, *Tanytarsus* sp. and Ceratopogonidae. The numbers varied, but were uniformly low at all places in the wet season, probably as a result of disturbance of the bottom during floods. In some places where flows were slack in the dry season, particularly at cattle drinking places, some Entomostraca appeared. These included the ostracod *Isocypris* sp., the cladocerans, *Simocephalus vetuloides*, *Ceriodaphania pulchella*, *Alona* cf. *quadrangula*, and the copepod *Paracyclops poppeyi*.

In the Valley Sand-Bed zone, with mixed sand and mud bed sediments, as typified by Mandini, the fauna consisted mainly of numbers of *Limnodrilus* sp. 1 and *Branchiura* cf. *sowerbyi*. Three additional species peculiar to the zone *Pentaneura* spp., *Chironomus* sp. and cf. *Tabanus* sp., further distinguished the fauna.

Finally, where mud predominated in sheltered places such as at Colenso, the fauna was dominated by the single species *Branchiura* cf. *sowerbyi*. Their numbers increased in December, February, April and July at Colenso.

9. SUMMARY OF THE FINDINGS.

The foregoing sections have described the environment and the fauna of the river in some detail. This section summarises the conditions and biology of the river and indicates the relationship between them.

(a) **The Tugela as a biological environment.**

The river has a variety of habitats. It rises in the Drakensberg mountains at a height of 10,400 ft. It soon descends steeply as a small, stony torrent (about 20 ft. wide), and then runs in a wide shallow valley with a bed predominantly of sand. The course of the river (now 240 ft. wide) is interrupted half-way down the basin by torrential rapids in a steepened section, resulting from rejuvenation. Thereafter it winds sea-wards through a broken valley, over a 1,000 ft. wide, sandy bed.

Conditions in the habitats varied considerably from season to season. During the survey the basin received a moderate rainfall, mostly in the wet summer months, when the discharge of the river was about eight times that of the dry season. Water temperatures

ranged between 3.3°C. to 21.1°C. in the headwaters, between — 1.1°C. and 28.9°C. in the mid river, and were highest nearest the mouth. The water was generally just above neutral (pH 7.3—7.8) but tended to become slightly more alkaline (pH 7.5—8.3) in the dry season, when the concentration of bicarbonates increased.

The chemical constitution of the water depended upon geological formations in the basin, influenced by the climate. Dissolved solids in the river were comparatively low at all times. Concentrations increased progressively downstream, and were highest in the dry season when the river was low. (32—108 ppm. in the wet season, 42—145 ppm. in the dry season). Bicarbonates of calcium and magnesium formed the bulk of the material at all times, accompanied by lesser amounts of sulphates, chloride, and sodium salts. These conditions recur from year to year (cf. CAPLAN, JACKSON, WEBB AND MIDDLETON (1952) Table A13.).

A most important feature about the river was the extreme variability in flow in different seasons. The speed of the current increased between two and five-fold during summer floods as compared with that in the winter dry season, and the load of silt increased from negligible amounts in the dry season to enormous amounts during floods.

The power of the floods caused wholesale movement of the bed in summer. In rapids, boulders rolled and shifted, and the river often changed course within its bed. Lower down the river the bottom tended to be composed of large boulders rather than stones, and such was the power of the current during high floods, that even these were heard rolling and grinding about. In slower-flowing, sandy reaches, the bed shifted continually during high flows, and some bank erosion took place. The extent of the disturbance during floods can be gauged from a number of observations: It was not uncommon to see a wall of muddy water 3—5 ft. high advancing downstream bearing trees, animals and detritus after summer storms. After such flooding, the amount of grass, brush and debris carried was so great that the surber sampler choked and filled within a few minutes of being placed in the river, and had to be fitted with a screen at its front edge, for operation in the summer. At the same time the bed load of rolling sand could be felt as a constant abrading stream near the bottom.

Changes in the volume of the river naturally caused changes in the area of the bed covered, and when full, the river covered about four times the area it did when at its lowest in the dry season.

The variations in the level of the river which occurred between floods in the wet season, led to cycles of exposure and inundation of banks and bed which continually altered the extent of habitats in the river.

These conditions had a profound influence on the flora and fauna in the wet season, and resulted in a reduction of numbers, sometimes to as little as 1/10th or 1/20th those of the dry season. A similar effect has also been recorded as a result of flooding in a number of rivers in the United Kingdom. (ERICKSEN JONES (1941, 1948, 1949,); (BUTCHER ET AL. (1937)); and in the Berg River in the Cape Province (HARRISON & ELSWORTH (1958)).

(b) **River Biology.**

Flora: — As a result of the rapid flows and erosion during the wet season, the flora of the river was restricted mainly to a few species of emergent marginal species; reeds (*Phragmites communis*), sedges (*Cyperus marginatus*), and grasses (*Cynodon dactylon*). Algae and diatoms became established in the river only in the late autumn (June) and winter, when the water cleared, the flow slowed and steadied, and the concentration of nutrients increased. A similar seasonal increase in algae in the Nile during low flows has been recorded by ABDIN (1946). Growth of algae became particularly prolific in the Tugela Ferry area in August and September and had a considerable influence on the fauna in the marginal vegetation. At National Park in the Upper river, however, growth of algae occurred also in the summer (November). This was possibly the result of relatively steady (though comparatively fast) flows, and the absence of appreciable amounts of silt in this region.

Fauna: — The communities of the main habitats in the various zones of the river are distinct, and have been described elsewhere. The fauna was composed usually of mayflies, (50—90 %), though numbers of Caddis-flies (5—50 %), *Simulium* spp. larvae (5—95 %), and Chironomidae (5—25 %) were sometimes present in the winter months.

The zonation of the species of the fauna has already been described. Some of the common species, however, were distributed widely in the river and were found in most zones. These species formed a common element in the fauna of all but the Upper river.

Those inhabiting the rapids were *Baetis harrisoni*, *Centroptilum excisum*, *Caenis* sp. 1, *Euthraulus elegans*, *Neurocaenis discolor*, *Neoperla spio*, *Cheumatopsyche zuluensis*, Elmidae sp. 1, Chironomidae spp., Ceratopogonidae spp. and *Rana fuscigula*.

Those inhabiting the marginal vegetation were: *Austrocaenis capensis*? *Baetis bellus*, *B.* sp. 2, *Pseudocloeon vinosum*, *Pseudagrion salisburyense*, *Microvelia major*, *Rhagovelia nigricans*, *Laccocoris limnigenus* and Chironomidae.

Those inhabiting the bottom sediments were: *Limnodrilus* sp. 1, *Branchiura* cf. *sowerbyi*, *Paragomphus cognatus* or *P. hageni*, Chi-

ronomidae, including *Procladius* spp. 1 and 2 and *Tanytarsus* sp., and Ceratopogonidae spp.

Fish Fauna: — The relation of the fish fauna of the river to the bottom fauna and flora has not been determined. It is recognised, however, that the fish must play an important part in limiting the fauna and flora, and they are forming the subject of a special study to be published later (Part 7 of the series).

The rainbow trout, *Salmo gairdnerii*, and the small catfish, *Amphilius natalensis*, were the more important species in the Lower Torrential zone. In the Sand Bed zones above Colenso, and in the Rejuvenated River zone, important species were the mud-fish, *Labeo rubromaculatus*, the barbus, *Barbus marequensis*, and in rapids the mud-fish *Labeo cylindricus*. Below these zones, in the Valley Sand Bed zone, the ,Barbel', *Clarias gariepinus*, became increasingly abundant, and predominated over other forms. In the last few miles of the zone, and in the estuary, representatives of marine groups, such as gobies (Gobiidae), mullets, (Mugilidae) and bream (Sparidae) were found. One of the gobies (*Gobius aeneofuscus*) was found particularly far upstream, in fresh water.

(c) **The relation of the Flora and Fauna to the Habitat.**

i. Zonation. — In general the headwaters of the mountain streams are mainly extended torrential rapids with a relatively restricted range of conditions; current speeds are relatively high and constant, temperatures are relatively low, the waters are comparatively pure and little silt is carried. The lower zones of the river, on the other hand, are more stable and have wide ranges of conditions; flows are more variable, temperatures and concentrations of dissolved substances are higher, and the amounts of silt are considerable at times.

A clear difference was found between the communities of the upper river zones and those of the other zones which comprise the greater part of the river. This difference was distinct both in the rapids and the marginal vegetation. For example, the typical community of the Upper Torrential zone comprised *Acentrella natalensis*, *Centroptilum sudafricanum*, *Afronurus harrisoni*, and *Cheumatopsyche maculata*. These were not found in the rapids in the zone of rejuvenation at Hart's Hill which has a comparable gradient, where the fauna was composed of *Elassoneuria trimeniana*, *Baetis harrisoni*, *Baetis* sp. 1., *Afronurus* sp. 1, *Euthraulus elegans*, *Caenis* spp., *Prosopistoma crassi*, *Hydropsyche ulmeri*, *Cheumatopsyche zuluensis* and *Tanytarsus* sp. 1. Further, the zones of the Upper river were short and clear, whereas those in the remainder were long and not quite so sharply defined. (See section 3).

These differences in faunae seem to depend mainly upon physical

features of the zones such as the temperature and rate of flow of the water and the gradients, and altitudes of the zones. It appears that the greatest differences in conditions between zones are those of temperature. The average water temperature at Colenso at the end of the Foothill Sand Bed zone, was 5°C. higher than that at National Park in the Mountain Torrent zone, and the range of temperature throughout the year was 14° greater. The average at Mandini at the end of the Valley Sand Bed zone, was 10° higher than at National Park.

The distribution of particular species are of interest in this connection: some were abundant at different times in different zones and their distributions seem to have been limited by some seasonal controlling factor, such as the temperature of the water, though the amount of silt and rates of flow may also have been important. Of course, low or high temperatures may not necessarily directly limit the presence of animals, but may control the life history of the species indirectly, by affecting the length of nymphal life, or by influencing the season and time of breeding, and oviposition, of the adult insects.

Species whose distributions were apparently influenced mainly by temperature included *Baetis harrisoni*, *B.* sp. 1., *Centroptilum indusii*, *Pseudagrion salisburyense* and *Rhagovelia nigricans*. (Table A15 in Appendix). These were common all year round in the upper river, but were found only in winter in the lower river, where summer temperatures were particularly high.

The zonation, however, is not simply dependant on temperature differences, and other factors, such as the availability of food, the rate of flow of the water, the concentration of dissolved materials, and silt, and gradient dependent factors, all have an influence on the distribution of the fauna. (The last-mentioned factors, it is perhaps worth recording, are particularly important during floods when the speed of the water over deeply-submerged, steplike rapids in the Sand Bed zones, is much greater than that in mountain torrents, largely as a result of the enormous volume of water lower in the river). Many of these factors are interrelated and probably operate in concert in setting conditions for the fauna.

Species whose distributions appear to have been influenced by factors such as rates of flow, or related factors were: *Austrocaenis capensis*? *Neurocaenis discolor*, *Aphelocheirus schoutendeni* and *Laccocoris limnigenus*. One other species, *Centroptilum medium*, was found in enormous numbers on one occasion in June, when there was presumably a particularly abundant food supply, as a result of the discharge of organic material from the Kraft paper mill at Mandini.

ii. Climatic Regions. — The physical and chemical differences

between zones with their characteristic florae and faunae suggest the possibility of grouping the zones into climatic regions: the Source, Waterfall, and Torrential zones forming a temperate upland section; the Foothill Sand Bed, and Rejuvenation zones forming a sub-tropical midland section, and the Lower Valley Sand Bed zone forming a tropical lowland section.

The distinctive fauna of the temperate upland section is that typical of mountain streams (cf. section 8,) and includes such species as *Aphanicercella* sp., *Pseudocloeon inzingae*, *Baetis cataractae*, *Acentrella natalensis*, *A. monticola*, *Centroptilum sudafricanum*, *Aprionyx tricuspidatus*, *Adenophlebia auriculata*, *A. sylvatica*, *Afronurus harrisoni*, *Cheumatopsyche maculata*, *C.* sp. near *maculata*, *Scirtes* sp., *Elporia hiemis*, *E. natalensis*, *E. scruposa*, *Simulium debegene*, *S. dentulosum*, *S. nigritarsus* and *S. unicornutum*.

The distinctive fauna of rapids in the subtropical middle section (section 8) includes *Neoperla spio*, *Prosopistoma crassi*, *Elassoneuria trimeniana*, *Baetis harrisoni*, *B.* sp. 1., *Centroptilum indusii*, *Centroptiloides bifasciata*, *Neurocaenis discolor*, *Euthraulus elegans*, *Afronurus* sp., *Polymorphanisus bipunctatus*, *Elporia flavopicta*, *Simulium bovis* and *S. damnosum*. Distinctive species in marginal vegetation, which is more extensive in this region than in the previous one, are *Pseudocloeon vinosum*, *Baetis bellus*, *B.* sp. 2., *Austrocaenis capensis*? *Notoneurus cooperi*, *Pseudagrion salisburyense* and *Paragomphus cognatus*.

The distinctive fauna of the tropical lowland region includes *Prosopistoma* sp. 1., *Elassoneuria trimeniana*, *Baetis* sp. 1., *Centroptilum indusii*, *C.* sp. 1., *Caenis* sp. 1., *Neurocaenis discolor*, *Euthraulus elegans*, *Afronurus* sp. 1., *Mesogomphus* sp. 1., *Cheumatopsyche zuluensis* and *C. triangularis*. However many of these species occur in the subtropical middle section as well, and it seems that the tropical lowland element is only partly developed in the Tugela river. In this connection it is interesting to note that BRINK (1955) has indicated a transition in Natal between tropical and sub-tropical species of Gyrinidae in the North East, and temperate species in the South West, with a limit dividing the lowest part of the Tugela from the rest of the basin.

The physical conditions in the regions however are not sufficiently accurately known to define the regions clearly, and the climatic terms are being strained somewhat to indicate the differences between the zones.

iii. Rejuvenation. — The rejuvenation of the river below Colenso mentioned previously, had an interesting influence on the distribution of the trycorythid mayfly, *Neurocaenis discolor*. This was common in the Foothill Torrential zone, but was not well represented in

the more stable rapids of the Foothill Sand Bed zone, and the presence of extensive torrents below Colenso led to the reappearance of the species in numbers. The distribution of this particular species thus appears to be governed more by current speeds than by temperature and concentration factors (cf. HARRISON & ELSWORTH (1958)).

iv. Population Density. — The general trend of numbers in the rapids was almost exactly in inverse proportion to the rates of flow except in the upper river. Numbers were lowest in February, when the flow reached its highest value, and were highest in August when the flow was lowest. (Figures 4 and 6, and Table A14).

The densities of the faunae in the marginal vegetation varied in a somwehat similar way but were highest in spring and autumn. At some places they remained high throughout the winter, at others they dropped in mid-winter. The high densities seem to be related to lower rates of flow. During the high flows of summer the fauna was denser comparatively than that of the stony rapids, doubtless because the environment was less exposed, and was subject to washaways only during exceptional floods.

Variations in faunal density generally appear to follow changes in the rate of flow of the river. They probably depend most directly upon the adverse effects of flooding and silt in the wet season on the one hand, and upon the establishment cf steady flow conditions, and of algae during the dry season, on the other.

v. The relation of particular species to the habitat. — The distributions of some related species are of interest as confirmation of the ecological generalization that closely related species do not occupy the same niche. Where closely related species of a genus inhabited the stony bottoms of rapids, they were usually found in different zones, which did not overlap much, if at all, e.g. the three species of *Afronurus*: *A. harrisoni*, *A. peringueyi* and *A.* sp. 1. occupied separate zones in the Upper Torrential, Lower Torrential and Sand Bed zones respectively, and the two species of *Prosopistoma*, occupied different zones in the Foothill and Valley Sand Bed zones respectively.

A second point of interest is that species inhabiting the rapids were much more specific in their distributions than those inhabiting either the marginal vegetation or the bottom sediments, as can be seen in Table 12. The marginal vegetation and the bottom sediments are perhaps more uniform habitats than the rapids, but are subject to the same variations of temperature, concentration, rates of flow and the observation is puzzling, if not fortuitous.

10. COMPARISONS WITH OTHER RIVERS.

(a) **Physico-chemical conditions.**

The conditions and seasonal cycles in the Tugela river showed resemblances to those recorded in a number of other rivers; such as the upper waters of the Vaal above Vaaldam, which has a catchment similar in geology and climate to the Tugela (STANDER, BARNARD ET AL. (1952), unpublished report of C.S.I.R.); the Nile (HURST, (1952)), the Ohio (STREETER & FROST, (1924)); and the Tees, (BUTCHER, LONGWELL & PENTLOW, (1937)). Table A16).

However, conditions in the Great Berg river in the Cape Province, (HARRISON & ELSWORTH, (1958)), the only South African river which has yet been studied in any detail, differed from the Tugela in that,

i. high flows occurred in the winter because it is in a winter rainfall area,
ii. the concentration of dissolved solids varied more between the wet and dry seasons,
iii. the waters of the upper river were acidic, and
iv. the dissolved solids were mainly chlorides and not bicarbonates.

(b) **Fauna.**

The numbers of animals collected from the Tugela compare well with those recorded by other workers from other rivers. For instance, PERCIVAL & WHITEHEAD (1929), obtained average numbers of between 30 and 40 individuals per square dm. in beds of loose stones in streams in the West Riding of Yorkshire. These were a little higher than the average numbers of 25 per square dm. in comparable rapids at Estcourt, and 27 per square dm. in the Upper Torrential zone of the Tugela. (Fine Mesh Net). BERG (1948) has recorded average numbers of 13,000—18,000 per square meter of bottom sediments in zones I, II, III and IV in his study of the Danish river, Susaa (mesh 0.6 mm.) which can be compared with average numbers of 12,000 individuals per square meter collected from bottom sediments in the Bushmans river at Estcourt. (The average number of 1,800 per square meter obtained by coarse net in the Tugela river was very much lower). ALLEN (1951) has recorded numbers in the Horokiwi Stream in New Zealand, intermediate between those taken by coarse and fine net in the Tugela river. Finally, HARRISON & ELSWORTH (1958) obtained similar numbers of animals (comparing coarse net catches) in the Berg river, except at one abnormal station. It thus appears that the productivity in the Tugela is in line with that in other rivers.

Species Composition: — Compared with corresponding zones in the Tugela river, the upper zones in the Berg river (1—111b) (HARRISON & ELSWORTH (1959)) were much longer and the lower zones were

much shorter than those in the Tugela, and were hardly complicated by rejuvenation, except at Piquetberg (cf. HARRISON & ELSWORTH (1958)); This was probably due to the lower altitude (6,000 ft.) and uncomplicated gradient of the Berg.

Conditions in the Great Berg river also differed in a number of respects, particularly in the Upper acidic reaches, and it is not surprising to find the faunae of the two rivers somewhat different. (Table 13 shows the relationship between the zones in the rivers).

In the source zone of the Great Berg, Hydraenidae, Helodidae, Dryopidae and Helmidae were well represented, but Ephemeroptera were not. The corresponding zone in the Tugela in contrast, had considerable numbers of Ephemeroptera and comparatively few Coleoptera. In the Mountain Torrent zones of both rivers, although Ephemeroptera dominated the faunae, the species present in each were almost all different, and one family, the Ephemerellidae, was not represented at all in the Tugela. In addition, Nemouridae were few in the Tugela, whereas they were important in the Berg river. On the other hand, the faunae of the lower zones of the two rivers, which were neutral to alkaline, had many species in common (Table 14). However, a number of species characteristic of the lower Tugela were not found in the Great Berg — and may prove to be subtropical and tropical forms. These include *Prosopistoma crassi*, *P.* sp. 1., *Elassoneuria trimeniana*, *Centroptilum indusii*, *C.* sp. 1., *Centroptiloides bifasciatum*, *Cheumatopsyche triangularis*, *Polymorphanisus bipunctatus*, *Paragomphus hageni*, etc. (see p. 47 et sec.). (The flood plain of the Berg river has no counterpart in the Tugela and so no comparison is possible).

The fauna of a second African river that may be compared with the Tugela is that of the Sagana river in Kenya, recorded by VAN SOMEREN (1952). The study was confined to that part between the altitudes of 5,600 and 7.500 ft. and as no mention is made of the net used, it is not possible to be sure if the catches are comparable. *Baetis* spp. and *Simulium* spp. were the main components of the fauna. Most of the species identified were mayflies which are also found in the Lower Torrential zone, and the beginning of the Foothill Sand Bed zone of the Tugela. (The Odonata and *Simulium* spp. described are not known from the Tugela).

These observations illustrate the tendency for mountain forms to be restricted to higher altitudes towards the tropics, for the Lower Torrential zones were located at greater altitudes in each of the three rivers; the zone lies at about 1,000 ft. in the Berg; at about 4,500 ft. in the Tugela, and at about 7,000 ft. in the Sagana river, and these rivers are located 33°, 29° and $\frac{1}{2}$° of latitude south of the Equator respectively. The effect may partly be due to differences of altitude,

and also partly to differences in climatic conditions.

These few comparisons are inadequate to indicate the relationship of the fauna and flora of the Tugela with other South Africans rivers. General observations, however, suggest that conditions in most of the Tugela resemble those in the neutral to alkaline waters of the Cape, and Transvaal high-veld, and the Highlands of Kenya. Conditions in the Lower Valley Sand Bed zone, however, are related to those in rivers of the lowlands of Zululand, Swaziland, the Transvaal low-veld, and perhaps of East Africa as well. The Tugela thus seems to occupy a place transitional between temperate and sub-tropical conditions.

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TABLE 1
Average rates of flow estimated in the main river in cusecs

Station Number	Point	Source of Estimate	Season of High Flows	Season of Low Flows	Season of High Flows
			1954 - 1955	1954	1953 - 1954
T2	National Park	Half Mlambonjwa flow	258	25	213
M1	Mlambonjwa	Full flow gauge	515	50	425
T5	Bergville	Limited capacity gauge	1150 * (3546)	124	(1676)
T10	Colenso	Limited capacity gauge	3156 * (10874)	204	2106 * (5139)
T12a	Nkasini	Sum of gaugings of Colenso, Bushmans, Blaauwkrantz	4466 *	347 *	
T14	Tugela Ferry	Full flow gauge	13296	1535	6048
T16	Below Ngobevu	Sum of gaugings of Tugela Ferry, Mooi and Buffalo	17730	1932	8379
T19	Mandini	Estimated from Tugela Ferry, Mooi and Buffalo, + $\frac{1}{3}$	(23640)	(2576)	(11172)

* = Measurement from weir of limited capacity.
Figures in brackets ( ) are calculated Full Flows.

TABLE 2
Accuracy of chemical methods

(Based on information in standard works)

	ppm.
Total dissolved solids	1
Suspended solids	1
Oxygen absorbed from Permanganate (4 hrs.)	0.4
Alkalinity	1
Calcium	1
Magnesium	1
Nitrite	0.002
Nitrate	0.04
Phosphate	0.2
Free and saline ammonia	0.1
Sulphate	0.8
Chloride	0.4

TABLE 3
The reliability of sampling methods.
Coefficients of variation ($s/\bar{x}$) reported in literature, expressed as percentages

Author	Sampler used	Group (n)	Percentage coefficient of variation
Allen, K.R. (1951)	Scoop Net.	Heteropsyche (17)	71
		Pycnocentrodes (12)	81, 113
		Delantidium (18)	48
Leonard, J. W. (1939)	?	5 most common species	20 - 48^{+}
Leonard, J. W.		(5 samples)	23^{+}
Leonard, J. W.		(10 samples)	18^{+}
Macan, T. T. (1958)	Shovel Net.	Rhithrogena (4)	20
Mattley et al. (1939)	-		58
Needham, P.R. (1934)	-	(10)	62
Needham, P.R. and	Surber	All species : numbers	56
Usinger, R.L. (1956)	Surber	All species : weights	78
Surber, E.W. (1937)	Surber	Gammarus (3)	26 - 36

+ = Coefficients of variation of means ($\frac{s}{\bar{x}}/\bar{x}$)

TABLE 4
The reliability of the sampling methods

The deviations expected with 95% probability of correctness, for means based on particular numbers of sub-samples, ($\pm t_{.05}\ S\bar{x}$) expressed as percentages of the means. (all values ±)

HABITATS							
	STONES IN CURRENT		MARGINAL VEGETATION				
	Tugela at Oliviershoek Bridge		Umgeni at Albert Falls			Bushmans at Estcourt	
	Total Numbers	Numbers of Ephemeroptera	Total Numbers	Numbers of Ephemeroptera	Baetis bellus	Total Numbers	Total Numbers
Number of Samples and Units	9 of 1 sq. ft.	9 of 1 sq. ft.	10 of 5 ft.	10 of 5 ft.		6 of 5 ft.	4 of 10 ft.
Mean based on 3 sub-samples	136	122	84	162	99	81	69
Mean based on 5 sub-samples	68	57	39	75	46	37	-
Mean based on 4 sub-samples	-	-	-	-	-	-	39
Coefficient of Variation % $\frac{(s)}{(\bar{x})}$	55	49	34	65	40	33	28

TABLE 5

Monthly water temperatures in degrees centigrade

POINT	JULY					OCTOBER					JANUARY					FEBRUARY					APRIL				
	Average daily	Average daily minimum	Average daily maximum	Highest during month	Lowest during month	Average daily	Average daily minimum	Average daily maximum	Highest during month	Lowest during month	Average daily	Average daily minimum	Average daily maximum	Highest during month	Lowest during month	Average daily	Average daily minimum	Average daily maximum	Highest during month	Lowest during month	Average daily	Average daily minimum	Average daily maximum	Highest during month	Lowest during month
Mahai Hatchery National Park	7.2	4.9	9.2	11.7	3.3	13.6	10.5	16.7	18.3	8.3	16.4	13.2	19.6	21.1	11.1	17.2	14.5	19.9	22.2	12.8	13.9	11.1	16.7	18.9	10
Colenso Power Station Intake	12.2					20.6					23.1					21.4					20				
Estcourt	7.8	4.3	9.1	13.3	-1.1	16.4	12.1	21.6	30	8.9	19.8	16.2	23.3	28.9	14.4	20.2	18.6	21.7	28.9	14.4	14.8	12.9	16.6	17.8	8.9
Mandini	(17)					(27)					(25)					(25)					(25)				

Figures in brackets are measurements made in the field by the author on a single occasion during the month.

TABLE 9

Month	Average Percentage Silt
October	0.01
November	0.08
December	0.43
January	0.07
February	0.48
March	0.21
April	0.03
May	0.002
8 month average	0.29
Estimated annual percentage : 0.25	

TABLE 10
Silt load : 1955 - 1956

Position	BERGVILLE		COLENSO		MANDINI	
Month	Flow in cusecs.	Silt Load in Tons	Flow in cusecs.	Silt Load in Tons	Flow in cusecs.	Silt Load in Tons
October	-	-	-	-	420	4139
November	382	1503	288	2590	565	33853
December	621	20787	1714	118134	5784	1,854,557
January	344	26817	648	20061	1042	55,275
February	2571	314317	5313	979038	13855	4,450,687
March	1947	113563	9235	652149	15112	2,353,512
April	487	872	1651	8351	5003	122,408
May	-	-	-	-	960	1709
SIX-MONTHLY TOTAL: (tons)		478,000		1,780,323		8,870,292
AVERAGE RATE OF FLOW OVER SIX MONTHS: (cusecs.)	1040		3142		6893	
TOTAL ANNUAL LOAD: (tons)		478,000		1,780,323		8,876,140
PERCENTAGE OF TOTAL CATCHMENT AREA ABOVE GAUGING POINT:	5.9		14.4		100	

TABLE 11
Contributions of sections of the basin to flows and silt loads in the wet season of 1955 - 195

Section	Catchment Areas as percentage of area of the basin	Average rates of flow in summer as percentage of the average at Mandini	Total Silt Load in summer as percentage of the total load at Mandini	Tons of Sil per square mile of catchment above sectio
Above Bergville	5.9	15.1	5.4	728
Bergville to Colenso	8.5	30.5	14.6	1854
Colenso to Mandini	85.6	544	80	867

TABLE 6

The average concentration of substances at various stations on the Tugela river during the wet

STATIONS	pH W.	pH D.	Conductivity in mmhos. W.	Conductivity in mmhos. D.	Total dissolved Solids in ppm. W.	Total dissolved Solids in ppm. D.	Oxygen absorbed from Permanganate (4 hours) in ppm. W.	Oxygen absorbed from Permanganate (4 hours) in ppm. D.	Free and Saline Ammonia in ppm. N. W.	Free and Saline Ammonia in ppm. N. D.	Nitrites in ppm. N. + W.	Nitrites in ppm. N. + D.	Nitrates in ppm. N. + W.	Nitrates in ppm. N. + D.	Phosphates in ppm. $+PO_4$ W.	Phosphates in ppm. $+PO_4$ D.
T1a. Above National Park	7.3	7.6	26	45	-	-	-	-	-	-	-	-	--	--	-	-
T2. National Park	7.3	7.5	27	40	32	42	0	-	0	0.2	.001		.05	.03	.2	0
T4. Oliviershoek Bridge	7.3	7.5	33	57	39	63	0.2	0.5	0	0	0	0	.06	.02	.2	0
T5. Bergville	7.4	7.5	36	58	38	73	0.3	0.9	0	.17	.003	.001	.09	0	.7	–
T6. Below Bergville	7.4	7.6	37	62	40	64	0.4	2	0	.2	.001	–	.15	–	.7	–
T7. Labuschagne's Kraal	7.4	7.6	41	77	48	-	2.2	-	0	.28	.004	–	.1	–	.8	–
T10. Colenso	7.4	7.7	41	89	48	71	0.6	1.1	0.04	.13	.004	.002	.1	.01	.5	0
T10a. Hart's Hill	7.5	7.8	45	92	50	72	1.1	-	.05	.28	-	–	-	–	–	–
T12. Nkasini	7.5	7.9	52	108	57	101	0.3	1.8	.06	.24	.002	.011	.6	.72	–	0
T12a. Below Nkasini	7.7	7.9	72	142	62	113	0	1.5	.11	.23	-	–	.24	–	–	–
T14. Tugela Ferry	7.8	8.0	109	286	86	202	1.8	2.1	.11	.14	-	0	.24	.07	–	–
T15. Ngobevu	7.7	8.2	118	269	93	180	2.0	7.4	.13	3.9	0	–	-	–		
T16. Below Ngobevu	7.8	8.3	110	262	99	167	2.1	0.9	.14	–	.012	.009	.32	0	–	–
T18. Middle Drift	7.7	8.1	118	238	97	168	3.2	5.5	.33	-	-	–	.24	.03	–	–
T19. Mandini	7.8	8.2	123	246	108	145	2.8	3.2	.12	.57	-	.009	.16	0	–	–
TRIBUTARIES																
Mahai	7.4	-	23	74	21	40	0.5	4	4.9	2.3	.004	–	.08	-	.2	–
Sandspruit	7.0	6.8	75	132	105	124	2.3	5.8	.15	.43	.004	0	.1	.08	1.4	–
Little Tugela	7.5	7.6	43	75	45	64	1.3	0.6	.07	0	.005	–	.06	-	.5	–
Blaauwkrantz	8.1	8.3	356	935	273	595	0.4	0.9	.13	.21	-	–	-	.08	–	0
Bushmans	7.9	8.1	89	191	80	128	0.2	1.8	.22	.41	-	.001	-	0	–	–
Sundays	-	-	-	-	152	236	0.8	7.2	0	.33	.025	–	.4	–	–	–
Mooi	7.7	8.1	99	273	77	200	0.6	2.3	.03	.80	-	0	-	.1	–	–
Buffalo	7.8	8.3	144	252	129	160	2.7	0.7	0	0	0	.001	.16	0	–	–

STATIONS	Sulphates in ppm. SO_4 W.	Sulphates in ppm. SO_4 D.	Chlorides in ppm. Cl. W.	Chlorides in ppm. Cl. D.	Total Alkalinity as ppm. Calcium Carbonate W.	Total Alkalinity as ppm. Calcium Carbonate D.	Calcium as ppm. Calcium Carbonate W.	Calcium as ppm. Calcium Carbonate D.	Magnesium as ppm. Calcium Carbonate W.	Magnesium as ppm. Calcium Carbonate D.	Sodium Alkalinity as ppm. Calcium Carbonate (by difference) W.	Sodium Alkalinity as ppm. Calcium Carbonate (by difference) D.	Average Daily Rates of Flow in cusecs W.	Average Daily Rates of Flow in cusecs D.	
T1a. Above National Park	–	–	-	-	-	-	-	-	-	-	-	-	-	-	UPPER RIVER REGION
T2. National Park	0	3	1	2	28	29	9.2	15.9	9.0	14.8	9.8	-	258	25	
T4. Oliviershoek Bridge	0.2	3.1	1.2	2	30	46	9.9	19.5	9.7	16.8	10.4	9.7			FOOTHILL SAND BED ZONE
T5. Bergville	0	0	1.2	2.7	32	59	11.3	18.5	11.0	15.8	9.7	24.7	3,546	124	
T6. Below Bergville	0	4	1.4	2.3	32	50	11.7	21.0	11.3	15.0	9.0	14			
T7. Labuschagne's Kraal	0	4	1.4	3	32	55	12.0	17.9	11.2	17.1	8.8	20.0			
T10. Colenso	1.6	1.8	1.6	3	43	61	14.2	30.3	11.8	23.7	17	7.0	10,874	204	
T10a. Hart's Hill	1.7	4	2.3	3	42	65	14.4	28.8	13.3	21.2	14.3	15			REJUVENATED RIVER ZONE
T12. Nkasini	4.5	6.4	2	3.5	44	79	16.0	42.1	15.5	23.9	12.5	13.0			
T12a. Below Nkasini	3	8.2	2	8.3	50	86	20.9	39.7	23.1	33.3	6.0	13.0			
T14. Tugela Ferry	4.0	23.3	2.8	15	67	155	26.7	47.3	26.1	49.3	14.2	58.4	13,296	1,535	
T15. Ngobevu	5	21.1	2.5	12.7	74	121	28.3	60.3	28.5	52.1	17.2	8.6			
T16. Below Ngobevu	4.8	26.4	3.8	13.3	76	123	34.2	55.5	33.8	50.0	8.0	17.5			VALLEY SAND BED ZONE
T18. Middle Drift	8.8	20.7	2.8	11.7	72	114	30.9	51.2	29.9	49.8	11.2	13.0			
T19. Mandini	10.7	17.0	3.7	12.6	73	104	30.3	49.3	30.2	47.1	12.5	7.6	23,640	2,576	
TRIBUTARIES															
Mahai	.4	0	1.4	3	25	39	6.5	17.9	7.3	3.1	11.2	18			
Sandspruit	2.6	10.3	2	7.6	64	90	25.5	33.4	25.3	25.6	13.2	31			
Little Tugela	0	0	1.8	1	32	61	11.9	26.3	11.0	14.7	9.1	20	824	80	
Blaauwkrantz	29	82.9	34.3	143	203	239	87.1	151.9	85.9	166.1	30	-	124	3	
Bushmans	2.8	7.6	2.5	9.8	54	102	26.7	50.7	24.5	33.5	2.8	17.8	1,186	140	
Sundays	18.3	59.4	16.7	22	123	109	29	70.0	48.6	57.3	45.4	-	520	88	
Mooi	0	13.2	3.8	11.2	58	149	27	57.2	25.6	53.4	5.4	38.4	1,109	98	
Buffalo	17.3	28.3	6	9.5	86	119	28.1	59.0	33.5	59.1	24.4	0.9	6,172	555	

0 = Not detected in normal analysis.
W = During the wet season.
D = During the dry season.
+ = Based on a few analyses only.

TABLE 12

The distribution of the animal species "of significance" found in the Tugela river

A. The fauna of Stony Bottoms in Rapids

Order	Family	Species	Zones 1	2	3	4	5	6	7
Turbellaria:	Planariidae:	Planariidae sp. 1	+	+	+	+	+	+	+
		Planariidae sp. 2	+	+	+	+	+		
Nematoda:		Nematoda spp.			+	+	+	+	
Oligochaeta:	Naididae:	Nais sp. 1	+	+	+	+	+	+	+
	Tubificidae:	Branchiura sp., cf. sowerbyi			+	+	+	+	+
		Limnodrilus sp. 1			+	+	+	+	+
	Lumbriculidae:	Lumbriculus? sp. 1			+	+	+	+	+
Isopoda:	Jaeridae:	Protojanira perbrincki (r)			+				
Amphipoda:	Gammaridae:	Crangonyx robertsii (r)	+						
Plecoptera:	Perlidae:	Neoperla spio			+	+	+	+	+
Ephemeroptera:	Prosopistomatidae:	Prosopistoma crassi					+	+	+
		Prosopistoma sp. 1							+
	Polymitarcidae:	Ephoron savigni					+		
	Oligoneuriidae:	Elassoneuria trimeniana					+	+	+
	Baetidae	Pseudocloeon inzingae			+	+	+		
		Pseudocloeon maculosum				+	+	-	-
		Baetis harrisoni			+	+	+	+	+
		B. lawrencei (r)	+						
		Baetis sp. 1					+	+	+
		Baetis parvulus (r)			+	+			
		Acentrella natalensis	+	+	+	+			
		Acentrella monticola			+				
		Centroptilum sudafricanum	+	+	+	+			
		C. excisum	+	+	+	+	+	+	+
		Centroptilum indusii				+	+	+	+
		Centroptilum parvum (r)			+	+			
		C. varium						+	+
		C. sp. 1 (r)						+	+
		C. sp. 2			+	+	+		
		Centroptiloides bifasciatum					-	+	+
	Brachycercidae:	Caenis sp. 1				-	+	+	+
		Caenis sp. 2			+	+	+	+	+
		Caenis sp. 3						+	
		Neurocaenis discolor			+	+	+	+	+
	Leptophlebiidae:	Aprionyx tricuspidatus (r)			+				
		Adenophlebia auriculata	+	+	+	+			
		A. sylvatica			+				
		Castanophlebia calida			+				
		Euthraulus elegans			+	+	+	+	+
	Ecdyonuridae:	Afronurus peringueyi				+	+		
		A. harrisoni			+				
		A. sp. 1					+	+	+
Odonata:	Aechnidae:	Aechna rileyi			+	+	+	+	
		Mesogomphus sp. 1 (r)						+	+
		Mesogomphus sp. 2					+	+	
	Libellulidae:	Zygonyx torrida (r)						+	+
		Zygonyx sp. 1						+	+
Hemiptera:	Naucoridae:	Aphelocheirus schoutedeni					+	+	+
Trichoptera:	Leptoceridae:	Oecetis sp. 2			+	+			
	Hydropsychidae:	Hydropsyche ulmeri				+	+	+	
		H. sp. 1				+	+	+	
		Cheumatopsyche zuluensis			+	+	+	+	+
		C. triangularis						+	+
		C. maculata			+	+			
		C. sp.			+	+	-		
		Polymorphanisus bipunctatus					+	+	
	Polycentropidae:	Dipseudopsis sp. 1				+	+		
	Hydroptilidae:	Hydroptila capensis			+	+	-	-	-
		H. sp. 1			+	+	+	+	+
		H. sp. 2			+				
Coleoptera:	Gyrinidae:	Gyrinidae larvae spp. (? Aulonogyrus abdominalis)				+	+	+	
	Elmidae:	Elmidae sp. 1		+	+	+	+	+	+
		E. sp. 2				+	+	-	
		E. sp. 3					+	+	
		E. sp. 4				+	+		
	Helodidae:	Scirtes? sp. 1	+	+	+				
	Halticidae:	Aphthona marshalli (r)						+	
Diptera:	Tipulidae:	Tipulidae sp. 1			+	+	+		
	Simuliidae:	Simulium bovis					+	+	+
		S. medusaeforme	+	+	+	+	+	+	
		S. damnosum				+	+	+	+
		S. debegene					+		
		S. dentulosum					+		
	Chironomidae:	Tanypodinae spp.	+	+	+	+	+	+	+
		Orthocladinae spp.	+	+	+	+	+	+	+
		Chironominae spp.	+	+	+	+	-		
	Chironomidae:	Chironomidae sp. 1						+	+
	Ceratopogonidae:	Ceratopogonidae sp. 1	+	+	+	+	+	+	+
	Tabanidae:	Tabanus? sp. 1				+	+		
Mollusca:	Ancylidae	Burnupia sp.							+
Anura:	Ranidae:	Rana umbraculata	+	+	-				

A few species which only just qualified for inclusion in the list have been distinguished by the symbol (r)

(+) Indicates common occurrence in the zone.
(-) Indicates rare occurrence in the zone.

B. The fauna of the Marginal Vegetation

Order	Family	Species	Zones 1	2	3	4	5	6	7
Oligochaeta:	Naididae:	Naidium sp. 1 (r)	+	+	+	+	+	+	·
	Tubificidae:	Limnodrilus sp 1				+	+	+	+
Cladocera:	Daphnidae:	Simocephalus capensis					+		
		S. vetuloides					+	+	+
Copepoda:	Cyclopidae:	Eucyclops euacantus							+
Decapoda:	Potamonidae:	Potamon dubius (r)					+		
		P. sidneyi		+	+	-			
	Altyidae:	Caridina typus							+
		C. nilotica				-	-	-	+
	Palaemonidae:	Macrobrachium lepidactylus (r)						+	+
		Macrobrachium idae cf. idella							+
		M. equidens							+
		M. petersii?							+
Ephemeroptera:	Baetidae:	Pseudocloeon vinosum				+	+	+	+
		Baetis bellus				+	+	+	+
		B. lawrencei (r)	+						
		B. sp. 2				+	+	+	+
		Centroptilum excisum				+	+	+	+
		C. varium				+	+		
	Brachycercidae:	Austrocaenis sp. c.f. capensis				+	+	+	+
	Ecdyonuridae:	Notonurus cooperi					+	+	+
Odonata:	Synlestidae:	Chlorolestes sp. 1				+			+
	Caenagriidae:	Pseudagrion salisburyense				+	+	+	+
		Pseudagrion sp. 1							+
	Chlorocyphidae:	Chlorocypha sp. 1 (r)					+	+	+
	Gomphidae:	Paragomphus hageni					+	+	+
	Aechnidae:	Mesogomphus sp. 2					+	+	
	Libellulidae:	Trithemis sp. 1				+	+	+	+
		T. sp. 2							+
Hemiptera:	Veliidae:	Microvelia major				+	+	+	+
		Rhagovelia nigricans				+	+	+	+
	Corixidae:	Micronecta piccanin (r)				+	+		
		Micronecta scutellaris (r)					+	+	+
	Pleidae:	Plea pullula (r)				+	+	+	+
	Naucoridae:	Laccocoris limnigenus				+	+	+	+
	Belostomidae:	Sphaerodema nepoides					+	+	+
Trichoptera:	Leptoceridae:	Athripsodes harrisoni				+	+		
		? Leptocerina spp. (r)					+	+	+
Lepidoptera:	Pyralididae:	Nymphula sp. 1 (r)					+	+	+
Coleoptèra	Gyrinidae:	Aulonogyrus abdominalis					+	+	+
		Orectogyrus conformis				+	+		
	Hydrophilidae:	Berosus sp. 1					+	+	-
	Hydraenidae:	Hydraenidae sp. 1					+	+	+
		Hydraenidae sp. 2 (r)	+						
	Elmidae:	Elmidae sp. 5 (r)	+						
		Elmidae sp. 16				+	+		
	Curculionidae:	Piezotrachelus magnirostris (r)					+		
Diptera:	Culicidae: Dixinae:	Dixa sp. 1 (prob. bicolor)				+	+		
	Simuliidae:	Simulium nigritarsis (r)	+						
	Chironomidae:	Pentaneura sp. 1	+	+	+	+	+	+	+
		Chironomidae spp.	+	+	+	+	+	+	+
		Tanypodinae spp.	+	+	+	+	+	+	+
		Rheotanytarsus sp. 1	+	+	+	+	+		
Mollusca:	Planorbidae:	Planorbis sp. cf. andersoni				+	+		
Anura:	Ranidae:	Rana fuscigula	+	+	+	+	+	+	+
		R. sp. 1				+	+	+	+
		R. umbraculata	+						

C. The fauna of the Bottom Sediments

Order	Family	Species	Zones 1	2	3	4	5	6	7
			Sediments rare						
Oligochaeta:	Naididae:	Nais sp. 1	+	+	+	+	+	+	+
	Tubificidae:	Branchiura sowerbyi?			+	+	+	+	+
		Limnodrilus sp. 1			+	+	+	+	+
	Lumbriculidae:	Lumbriculus sp. 1			+	+	+	+	+
Ephemeroptera:	Baetidae:	Baetis bellus					+	+	+
		Centroptilum venustrum					+	+	+
	Brachycercidae:	Austrocaenis capensis					+	+	+
Odonata:	Gomphidae:	Paragomphus hageni					+	+	+
Diptera:	Chironomidae:	Pentaneura spp.					+	+	+
		Procladius sp. 1					+		+
		Procladius sp. 2					+		+
		Chironomidae spp.					+		+
		Chironomus sp. 1							+
	Tabanidae:	Tabanus? sp. 2							+

TABLE 13

Berg river	Tugela river
1. Source zone (4,000-5,000 ft.)	Upper river (4,000-10,400 ft.)
a. Sponge	1. Source zone (10,000-10,400 ft.)
b. Cliff waterfalls	2. Waterfall zone (7,500-10,000 ft.)
2. Mountain Torrent zone (1,000-4,000 ft.)	3. Mountain Torrent zone (5,000-7,500 ft.)
3. a. Foothill, stony run zone (300-1,000 ft.)	4. Foothill Torrent zone (4,000-5,000 ft.)
b. Foothill, stony run zone (300-1,000 ft.)	
4. Foothill, soft bottom zone (0-300 ft.)	5. Foothill Sand Bed. (3,000-4,000 ft.)
	6. Rejuvenation zone (slow reaches) (1,380-3,000 ft.)
	7. Valley Sandy Bed zone (10-1,380 ft.)
5. Flood plain zone	—
6. Estuary	8. Estuary

TABLE 14

Common species in the faunae of the Berg and Tugela Rivers

"Significant" species peculiar to the Berg river	"Significant" species or types common to the Berg and Tugela rivers
1. Source zone	
Sponge areas	
Paramelita nigroculus (Ephemeroptera not present)	Helodid larvae Simulium medusaeformis Chironomidae
Kloof Waterfalls	
Lithogloea sp. Hydraenidae Dryopidae Helmidae	Simulium medusaeformis (Upland River) Chironomidae larvae Ceratopogonidae larvae
2. Mountain Torrential zone	
Nemouridae Pseudocloeon sp. A Acentrella capensis Aprionyx peterseni Lithogloea harrisoni L. penicillata Helodidae Elmidae Limnophila nox Elporia barnardi E. uniradius Simulium hessei	Aphanicerca sp. Pseudocloeon vinosum Baetis harrisoni Castanophlebia calida Afronurus harrisoni Pseudagrion sp.? Cheumatopsyche maculata
3a. Upper Foothill Torrential zone	
Aphanicerca sp. Aprionyx tabularis Chloroterpes nigrescens Lithogloea harrisoni L. penicillata Myspoleo agilis Elmidae Helodidae Elporia uniradius	Pseudocloeon vinosum Baetis harrisoni B. bellus B. sp. 2 Austrocaenis sp.? Castanophlebia calida Euthraulus elegans Afronurus harrisoni Pseudagrion spp. Aechna minuscula Paragomphus cognatus Cheumatopsyche maculata
3b. Lower Foothill Torrential zone	
Prostoma sp. Nais sp. Aphanicerca sp. Lithogloea harrisoni L. penicillata Lymnaea columella Ferrissia sp.	Simocephalus vetuloides S. capensis Austrocloeon virgiliae Pseudocloeon maculosum P. vinosum Baetis harrisoni B. sp. A B. bellus B. sp. 2 Centroptilum excisum C. pulchrum Austrocaenis sp. Neurocaenis discolor Afronurus harrisoni Pseudagrion sp. Aechna miniscula Nychia limpida Micronecta piccanin M. scutellaris Cheumatopsyche maculata

"Significant" species peculiar to the Berg river	"Significant" species or types common to the Berg and Tugela rivers
Foothill Soft Bottom zone	
Prostoma sp.	Nais sp.
Micronecta bleekiana	Stylaria fossularis
Nilobezzia capensis	Simocephalus vetuloides
	S. capensis
	Pseudocloeon vinosum
	P. maculosum
	Baetis harrisoni
	B. sp. 1
	B. bellus
	B. sp. 2
	C. excisum
	Austrocaenis sp.
	Neurocaenis discolor
	Pseudagrion sp.
	Aechna minuscula
	Paragomphus cognatus
	Nychia limpida
	Plea pullula
	Micronecta picannin
	M. scutellaris
	Laccocoris limnigenus
	Cheumatopsyche zuluensis
	Simulium bovis
	Ferrissia sp.
5. Flood Plain Zone	
Prostoma sp.	Stylaria fossularis
Hydrochus gemmatus	Pseudagrion sp.
	Micronecta spp.

TABLE A1
Areas of catchments in the Tugela River Basin

CATCHMENT	Area in Square Miles	Percentage of total Area	Cumulative Area in sq. miles	Cumulative Percentage Area
Mlambonjwa	192	1.7		
Venterspruit	64	0.6		
Upper Tugela (above Bergville)	657	5.9	657	5.9
Sandspruit	64	0.5		
Little Tugela	526	4.7		
Colenso Area (above Colenso)	370	3.3	1617	14.4
Klip	864	7.7		
Blaauwkrantz	293	2.6		
Upper Bushmans (above Estcourt)	337	3.0		
Lower Bushmans	413	3.7		
Bushmans: Total	750	6.7		
Sundays (above gauge)	351	3.1		
Sundays (lower)	619	5.5		
Sundays River-Total	970	8.7		
Nkasini Area	139	1.2		
Tugela Ferry Area	353	3.2	4986	44.5
Upper Mooi (above Mooi River)	379	3.4		
Lower Mooi	771	6.9		
Mooi - Total	1150	10.3		
Inadi	74	0.7		
Upper Buffalo (above de Jager's Drift)	2266	20.2		
Lower Buffalo	1724	15.4		
Buffalo - Total	3990	35.6		
Middle River (above Ngobevu)			10200	91.1
Insuzi	340.5	3.0		
Mfongosi	54.8	0.5		
Lower Tugela	604.7	5.4	11200	100

TABLE A2
Main characteristics of the geological formations in the Tugela River Basin.
(Information from du Toit, (1954)).
(The relative positions of the series are indicated in Figure 3)

SERIES	CHARACTERISTICS
Stormberg Series:	
Drakenberg Volcanic Beds	Basalts and Rhyolites
Cave Sandstone	1. Mainly quartzitic and feldspathic sandstones 2. Some irregular calcareous concretions at base
Red Beds	1. Red mudstones 2. Shales and red feldspathic sandstones with abundant calcareous nodules (barite)
Molteno Beds	1. Shales 2. Sandstones with calcareous concretions, pyrite and marcasite
Beaufort Series:	
Upper Beaufort Beds	1. Red mudstones and feldspathic sandstones 2. Blue and green shales 3. Abundant red calcaerous concretions
Mid. Beaufort Beds	Mudstones and feldspathic sandstones
Lower Beaufort Beds	1. Feldspathic sandstones 2. Mudstones and shales, carbonaceous shales and coal 3. Sometimes with calcareous nodules
Ecca Series:	
North Eastern Coal Measures	
Upper Ecca Beds	Soft blue shales with concretionary nodules or lenses of phosphate of lime
Middle Ecca Beds	1. Thick sandstones and grits, alternating with softer layers 2. Horizontal sheets of dolerite
Lower Ecca Shales	1. Dark fissile shales and flagstones 2. Occasional concretions and lenses of impure limestone or claybound ironstone
Dwyka Series:	
Boulder Beds	Tillite. Largely amygdaloidals with diabase inclusions: Many other inclusions
Table Mountain Series:	
Table Mountain Sandstone	1. Red quartzitic sandstones with pebbles of quartzite, jasper and green cherty rock 2. At base, some red clay-shales, micaceous sandy shales and flagstones
Primitive or Basement System:	
Tugela and Mfongosi systems	Basis larvas and tuffs Chlorite schists Limestones Homblendic schists Amphibolite Aplite Pegmatite Homblendic gneisses Quartz and mica schists

TABLE A3

Percentages of catchments in different rainfall zones

Rainfall Zones	CATCHMENTS													
	Upper Tugela	Mlambonjwa	Little Tugela	Bergville-Colenso Area	Sandspruit, Geluksburg, & Venter-spruit Areas	Klip	Blaauw-kranz	Bush-mans	Sun-days	Nkasini-Tugela Ferry Area	Mooi	Buffalo	Remain-der of Lower River	Whole Catchment
75"-	6.9	21.8	1.6					4.1			0.2			0.9
60 - 75	15.0	43.5	3.3					5.8			0.5			1.7
50 - 60	11.5	13.1	4.9					6.6			2.4	1.0	1.3	2.0
40 - 50	33.4	4.3	13.1		40.0	7.7	9.8	14.0			7.8	5.1	27.8	10.0
30 - 40	25.3	17.4	65.6	50.0	30.0	81.8	21.3	24.8	78.7		46.9	49.6	51.1	49.3
25 - 30	8.1		11.5	50.0	30.0	10.5	68.8	44.6	18.5	100.0	37.2	39.0	15.7	33.0
-25"									2.8		4.9	5.3	4.0	3.1
Mean Annual Rainfall (inches)	47.4	60.6	37.9	31.0	36.5	34.7	30.5	37.[illegible]	32.7	27.2	32.3	31.3	35.7	33.2
Mean Annual Rainfall (mm)	1204	1539	963	787	927	881	775	955	831	691	820	795	907	843
Mean Annual Rainfall in 1000's of Acre feet	1014	621	1063	612	249	1599	477	1504	1692	214	1981	6661	2045	20,232
5 to 7 year Average Annual Flow in 1000's of Acre feet (Sept. 1946-1955)		157					34	349	240		425	1158		4663
Average Annual Per cent run-off		25.3					7.1	23.2	14		21.4	17.3		23

The 'average' rainfall in catchments of the Tugela River in mm
1953 - 1954

Catchment	Oct.	Nov.	Dec.	Jan.	Feb	March	Apr.	May	June	July	Aug.	Sept.	Total	Average Annual Rainfall for area
Upper Tugela - Upper	92.0	158.4	189.1	167.9	203.2	214.1	30.7	60.6	11.3	0.2	2.2	77.6	1207	1262 *
Upper Tugela - Lower	45.9	82.9	87.2	78.1	160.7	100.5	26.5	49.4	15.2	2.7	0	58.8	845	822
Upper Bushmans	145.3	167.6	114.9	117.3	237.1	167.0	21.0	66.5	0	0.3	0	48.5	1086	1262
Upper Bushmans - Middle	41.2	131.5	99.2	68.4	118.0	51.6	41.4	49.5	0.4	0	1.2	65.4	668	738
Mooi - Middle	60.1	96.1	129.0	91.0	159.7	52.9	56.0	53.3	1.5	1.3	1.5	58.8	761	845
Mooi - Lower	24.8	115.3	57.6	102.1	96.3	63.0	39.9	59.1	6.7	0.7	1.7	73.0	640	682
Klip - Upper	45.2	139.2	113.7	105.1	260.1	120.9	20.6	52.3	19.8	0	0.5	84.0	961	854
Klip - Lower	36.0	112.6	46.7	103.5	95.3	91.2	77.3	20.4	3.0	1.1	0	63.2	650	691
Sundays River	31.4	119.7	91.4	97.8	230.4	119.5	23.4	54.1	11.2	0.7	0.2	69.9	850	902
Middle Tugela	36.0	92.0	112.5	61.0	249.3	68.2	27.4	41.9	6.0	0	0.1	68.5	763	805
Buffalo - Upper	33.6	14[illegible].5	98.0	114.5	161.1	123.5	33.2	39.2	9.6	0.8	0	70.8	827	897
Buffalo - Middle	36.5	147.2	55.8	79.4	151.9	75.4	29.7	42.3	6.2	0.8	3.8	59.5	689	796
Buffalo - Lower (1)	43.0	216.5	72.7	63.8	66.2	77.5	40.8	79.1	4.5	1.8	3.9	57.3	662	1048
Inadi	42.8	146.0	86.7	95.9	89.3	77.7	54.2	71.4	12.5	2.5	5.8	86.4	765	739
Qudeni Nkandhla - High	77.3	165.7	173.4	126.1	139.5	83.4	66.2	87.7	22.2	9.1	24.1	130.5	1105	1125
Lower Tugela	80.9	150.2	118.6	161.2	162.5	105.4	98.8	80.3	34.1	13.4	22.4	146.6	1174	1103

(* 1 station only)

TABLE A4

The 'average' rainfall in catchments of the Tugela River in mm
1954 - 1955

Catchment	Oct.	Nov.	Dec.	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Total
Upper Tugela - Upper	94.1	203.9	197.9	360.3	358.9	154.8	55.7	52.7	25.0	0.1	0	15.8	1519
Upper Tugela - Lower	84.6	172.4	95.8	204.4	208.1	72.8	38.4	27.0	0	0	0	7.0	886
Upper Bushmans	94.3	104.8	189.3	197.0	291.2	89.9	64.8	49.2	36.0	8.1	0	20.6	1146
Upper Bushmans - Middle	92.0	120.0	91.4	193.6	113.1	140.6	40.3	18.5	0	0	0	12.4	822
Mooi - Middle	101.0	117.4	100.4	207.4	98.8	72.7	52.8	29.0	2.1	0.6	0	20.7	803
Mooi - Lower	117.1	115.9	81.2	118.3	111.0	100.3	36.7	10.5	2.3	0	0	9.9	703
Klip - Upper	134.6	219.3	127.1	281.6	245.9	70.4	24.7	16.9	0	0.3	2.5	8.8	1132
Klip - Lower	78.7	118.9	106.1	139.8	150.6	60.7	37.4	12.1	0	0	0	9.4	713
Sundays River	129.2	192.0	70.7	257.6	180.5	68.2	29.2	8.3	2.5	0.2	0.8	10.2	949
Middle Tugela	101.0	151.6	70.6	170.4	167.5	57.5	22.8	9.3	0.1	0	0	4.7	756
Buffalo - Upper	97.4	143.1	78.5	190.2	221.9	103.8	25.2	15.2	2.1	2.4	2.6	7.8	890
Buffalo - Middle	114.5	167.0	69.4	208.0	166.1	78.2	25.6	10.7	2.5	0.5	3.1	6.6	853
Buffalo - Lower	121.5	118.5	28.9	139.2	108.6	113.3	30.3	7.5	0.1	0	0	33.7	702
Inadi	161.0	113.9	43.4	192.6	111.4	107.7	65.2	10.9	3.3	0	0	16.6	826
Qudeni Nkandhla-High	243.7	155.1	69.7	214.4	112.5	200.7	91.7	28.4	13.7	1.5	7.6	56.8	1196
Lower Tugela	265.6	136.1	202.0	237.1	119.1	104.4	114.2	20.6	19.9	1.6	4.5	61.5	1287

TABLE A5

Monthly average rates of flow recorded at different gauging weirs in the Tugela Basin - measured in cusecs

	1953 - 1954												1954 - 1955						
Month -	Oct.	Nov.	Dec.	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	Apr.
Mlambonjwa - 387	77	196	485	366	521	559	216	98	61	42	30	40	75	408	515	475	764	432	146
Bergville - 174	135	206+	360+	360+	360+	360+	344+	214	146	96	69	89	220	356+	360+	360+	360+	360+	349+
Blaauwkrantz - 457 (near Frere)	(under construction)			1:3	76	10.6	0	1.31	1.46	0.49	0	3.07	9.97	155	87	59	301	268	3.5
Colenso - 78	199	777	2155+	1729+	3100+	2824+	901	335	211	133	78	175	421	1719+	2987+	1856+	6447+	3246+	563
Bushmans River Estcourt - 211	71	107	561	366	545	445	191	162	84	62	40	44	85	483	508	427	790	514	173
Sundays River - 4?9 (at Meduna)	(under construction)			61	784	343	101	87	37	22	14.7	40	235	501	186	347	1282	400	83
Washbank - 355	(under construction)			23	137	126	15.7	24	14.4	13.4	13.4	31	81	222	54	149	419	131	27
Tugela Ferry - 153	812	1909	4366	4239	13580	6741	2186	1865	878	651	510	1513	4100	9083	8305	12743	27438	10142	1083
Mooi River Pump Station - 401 (average between Oct. 1950 and March 1954 when readings ceased)	49.9	124	379	690+	766+	491+	206	93	66.6	53.6	63.6	59.4	49.9	124	379	690+	766+	491+	206
Mooi River at Muden - 213 (average between Oct. 1947 and Sept. 1952 when readings ceased)	87.8	226	632	1082	923	1762	492	199.	84	64.3	92.5	82.2	87.8	226	632	1082	923	1762	492
Buffalo River at de Jagersdrift - 34?	153	659	1216	820	3051	1399	849	673	311	251	152	135	721	1695	950	218	11799	3608	714
Sum of Tugela Ferry, Mooi and Buffalo River flows:	1053	2794	6214	6141	17554	9902	3527	2737	1273	966	755	1730	4909	11004	9887	14043	40160	15512	2289
year average for Tugela Ferry (Sept. 1946 - Sept. 1953)	1401	2832	4237	5793	7582	8190	3004	1433	932	751	671	806							

indicates weir submerged at high flows: the values are thus highest recorded flows and not total flows

TABLE A6
Supplementary data on flows

(i) Average rates of flow at Tugela Ferry in cusecs

	Summer (Oct.-March)	High flow	Winter (April-Sept.)	Low flow	Whole year
7 year average Sept. 1946 - Sept. 1953	4975	5709	1261	912	3112
1953-1954	5156	6048	1263	1535	3204
1954-1955	11729	13296	-	-	-

(ii) Average rate of flow gauged at new weir at Mandini

Year	High flow	Low flow
1955-1956	7229	-
1956-1957	14538	1159

(iii) Relative flows at stations on the Tugela River as a percentage of the total flow of the

STATION	Year 1953-'54	High flow 1953-'54	Low flow 1954	Summer 1954-'55	High flow 1954-'55	Summ 1955-
Bergville	4.2 *	-	4.4	2.4 *	5.1	15
Colenso	19.6 *	19.3	7.3	17.6 *	13.9	46
Tugela Ferry **	60.8	55.5	55.1	74.7	58.4	59

* Flow based on weirs of limited capacity.
** Flow based on rated river run with sand bottom.

(iv) Percentage run-off

The percentage of annual rainfall measured ultimately flowing in the river

	% Run-off	% of whole Catchment area
Mlambonjwa	25	1.7
Bergville	45.6	5.9
Colenso	62.9	14.4
Tugela Ferry	36.6	44.5
Mandini	23	100

TABLE A7

Estimated average rates of flow in particular river catchments

AREA	WET SEASON: 1954-'55 Flow in cusecs	% of Total flow	DRY SEASON: 1954 Flow in cusecs	% of Total flow
Above National Park *	258	1.1	25	1.0
Mlambonjwa	515	2.2	50	1.9
Remainder above Bergville	2773	11.7	49	1.9
Little Tugela *	824	3.5	80	3.1
Remainder above Colenso	6504	27.5	0	0
Blaauwkrantz	124	0.5	3	0.1
Bushmans	1186	5.0	140	5.4
Sundays	520	2.2	88	3.4
Local areas between Colenso-Tugela Ferry (including Klip)	592	2.5	1100	42.8
Mooi	1109	4.7	98	3.8
Buffalo	6172	26.1	555	21.5
Lower River (below Ngobevu)	3063	13.0	388	15.1
TOTAL:	23640		2576	

* Reliability doubtful.

TABLE A8
Contamination of the Tugela River

Locality	Source	Type	Season when important	Local effect	Length of Tugela River affected
TUGELA RIVER:					
1. Tugela Ferry area	Local drainage on banks	Inorganic	Winter only	Banks of tributaries and main river affected for miles by local seepage water with high T.D.S. Crystallisation of salts occurs on banks	
2. Bond's Drift	Paper and pulp making factory effluent	Organic and Inorganic	Winter only	½ mile of north bank affected	½ mile of north bank affected
TUGELA TRIBUTARIES:					
3. Mahai at National Park	Sewage disposal plant effluent	Organic	Winter only	1 mile of Mahai affected	Practically unaffected
4. Sandspruit below Bergville	1. Milk processing factory waste 2. School septic tank effluent	Organic	Mainly winter	½ mile of stream severely affected	½ mile
5. Stream below Colenso	1. Sewage disposal plant effluent 2. Drainage from Native Township	Organic	Winter, when river is low	Stream severely affected	1 mile
	3. Power Station	Cooling water	Winter only	Temperature raised 5^{o}	½ mile
6. Blaauwkrantz stream	1. Weenen irrigation overflow 2. Soils of basin	Inorganic	Winter and Summer	Stream carries comparatively high load of dissolved solids	No effect

TABLE A8 (continued)
Contamination of the Tugela River

Locality	Source	Type	Season when important	Local effect	
TUGELA TRIBUTARIES:					
7. Little Bushmans river	1. Waste disposal farm effluents	Organic and inorganic	Winter	Slight disturbance of fauna and flora	
	2. Board factory effluents	Organic and inorganic	Winter	½ mile of river heavily polluted	
	3. Milk processing factory effluent	Organic and inorganic	Winter	½ mile of river heavily polluted	
8. Bushmans river	1. Little Bushmans river	Organic and inorganic	Winter	1 mile of river slightly affected	
	2. Sewage disposal farm effluent	Organic and inorganic	Winter	5 - 10 miles of river affected	
	3. Overflow from Weenen Irrigation	Organic and inorganic	Winter	5 miles of river affected	
9. Sundays river: (a) Inkunzi river					
Wesselsnek stream	1. Natal Steam Coal Colliery effluents	Mineral	Winter and summer, greatest effect in winter	No life in local stream	Small volume
Washbank river	2. By-products factory effluent from Slimes dam	Mineral	- do -	- do -	- do -
Washbank river	3. By-products colliery effluent	Mineral	- do -	- do -	- do -
Burnside stream	4. Natal Navigation Colliery effluent	Mineral	- do -	Disturbance of fauna and flora	- do -
Burnside stream	5. Burnside Colliery effluent	Mineral	- do -	5 miles of river affected	Large volume
(b) Sundays river	6. Newcastle-Platberg Colliery effluent	Mineral	- do -	Disturbance of fauna and flora	Small volume
	7 Elandslaagte stream from slag dumps	Mineral	- do -	- do -	- do -

1. Monthly mean temperatures at the Mahai Hatchery at National Park in °C.

	1956 May	1956 June	1956 July	1956 Aug.	1956 Sept.	1956 Oct.	1956 Nov.	1956 Dec.	1957 Jan.	1957 Feb.	1957 March	1957 April
Mean of maximum daily air temp.	-	17.4	16.9	19.7	19.4	22.8	21.6	22.8	26.2	26.2	24.4	21.6
Mean of minimum daily air temp.	-	4.7	5.1	8.1	8.8	12.3	12.7	12.2	15.3	16.4	15.4	12.8
Mean of maximum daily water temp.	11.8	9.6	9.2	11.2	13.6	16.7	16.2	18.0	19.6	19.9	18.8	16.7
Mean of minimum daily water temp.	7.9	5.1	4.9	6.8	7.4	10.5	11.5	11.5	13.2	14.5	13.9	11.1
Highest maximum water temp.	16.7	12.2	11.7	13.3	16.7	18.3	17.8	19.4	21.1	22.2	20.6	18.9
Lowest maximum water temp.	8.3	6.7	8.3	9.4	11.7	14.4	15.0	16.1	17.8	18.9	15.6	13.9
Highest minimum water temp.	11.7	6.7	7.8	8.9	8.9	14.4	13.3	12.8	15.6	15.6	15.6	13.3
Lowest minimum water temp.	4.4	2.2	3.3	4.4	5.6	8.3	10.0	10.6	11.1	12.8	12.8	10

2. Monthly mean water temperatures at Estcourt

	1955 July	1955 Aug.	1955 Sept.	1954 Oct.	1954 Nov.	1955 Jan.	1956 Feb.	1956 March	1956 April
1. Mean of daily maximum	9.1	10.7	10.4	21.6	19.9	23.3	21.7	18.7	16.6
2. Mean of daily minimum	4.3	4.4	7.2	12.1	13.6	16.2	18.6	15.9	12.9
3. Highest maximum	13.3	15.6	16.7	30.0	25.8	28.9	28.9	22.2	17.8
4. Lowest maximum	5.6	4.4	4.4	15.6	16.7	21.1	18.9	16.7	14.4
5. Highest minimum	10.0	10.0	11.1	14.4	16.7	18.9	22.2	17.8	16.7
6. Lowest minimum	-1.1	-1.1	2.2	8.9	11.1	14.4	14.4	12.8	8.9

(a) Monthly mean water temperatures at Colenso *

Year	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April
1952 - 1953					21.7	27.2	25.6	22.2	23.3	23.3	22.2	19.4
1954 - 1955	17.2	12.2	12.8	16.1	23.9	20.6	20.0	21.7	22.8	19.4	20.6	20.6
1955	16.7	12.8	11.1	14.4	21.7	23.3	25.0	21.7				

(b) Average diurnal temperatures during December, 1954 at Colenso

12 midnight	6 a.m.	12 noon	6 p.m.
22.3	21.7	21.9	22.5

* During the dry season the temperature of the river water rises a few degrees as a result of the circulation of cooling water from the power station.

The speed of the current in the river at various points in cm. per sec.
(Averages based on a number of measurements during each season)

STATION	RAPIDS				UNIMPEDED FLOW DURING FLOODS	MARGINAL VEGETATION	
	SUMMER		WINTER				
	Unimpeded flow	Amongst stones	Unimpeded flow	Amongst stones		Summer	Winter
1a. Above National Park	79	15	30	8	152+	3	-
2. National Park	84	30	30	15	152+	3	-
4. Oliviershoek Bridge	76	52	61	8	-	3	0 - 6
5. Bergville	79	30	61	15	244+	15	0 - 11
7. Labuschagne's Kraal	70	24	61	30	-	0	-
10. Colenso	85	34	64	30	305	3	0 - 2.6
12. Nkasini	82	27	79	0.5 - 15	-	1.5	-
14. Tugela Ferry	87	40	76	40	-	3	0 - 3
15. Ngobevu	78	65	61	34	-	3	0 - 10
18. Middle Drift	84	56	88	15	-	2.4	0
19. Mandini	70	51	64	61	253	1.5	0

0 = Not measurable.

TABLE A11

The average composition of the underground waters in particular geological formations
(Information from Bond - 1946)

GEOLOGICAL FORMATION	pH	Dissolved Solids in ppm.	AS PERCENTAGE OF TOTAL DISSOLVED SOLIDS							
			Sulphates	Chlorides	Total Hardness as Calcium Carbonate	Permanent Hardness as Calcium Carbonate	Calcium as Calcium Oxide	Magnesium as Magnesium Oxide	Soda Alkalinity as Sodium Carbonate	Silica
1. Stormberg lavas	7.7	417	0.8	6.6	52.7	0	15.8	10.7	14.7	12.2
2. Stormberg feldspathic sandstones	7.8	384	1.8	6.3	50.6	0	15.4	10.5	30.3	8.3
3 Mid and Upper Beaufort	8.2	357	5.3	5.7	39.5	0	12.5	7.7	37.3	6.4
4 Lower Beaufort	7.6	1060	10.6	26.1	52.5	20.5	14.8	10.4	0	3.8
5. Northern Natal Ecca Beds *	6.5 - 8.2	51 - 820	0 - 25	3 - 30	8.7 - 89	0 - 46.5	2.5 - 25	2.6 - 19	0	2 - 17.6
6. Natal Coast Ecca Beds	7.5	1814	2.5	51.2	38.8	26.0	5.3	11.7	0	1.2
7. Dwyka tillite	6.8 - 8	447	1.5	27.2	44.3	3.0	14.9	10.0	0	5.9
8 Table Mountain sandstones	6.9	114	2.1	32.1	33.3	16.3	6.8	10.2	0	10.4
9 Old granite and gneiss	7.3	364	3.2	32.0	30 0	12.7	7.3	9.1	0	10.2

* Very variable - no average calculated.

TABLE A12

Plants commonly found on the banks forming the typical marginal vegetation of the river

The list, which does not attempt to cover all the riverbank species, is based on collections made at various stations and also on lists compiled by Mr. D. Edwards, Natal Provincial Plant Ecology Fellow, to whom grateful acknowledgement is made.

SPECIES	Type	Upper River Region: Montane	Upper River Region: L.T. Zone	Upper River Zone	(Valley Zone) Middle River and Top of Lower River Zone	(Coastal) Lower River Zone
Non-Flowering Vascular Plants (after Sim. 1915)						
Equisetaceae						
Equisetum ramosissimum Desf.	R		+	+	+	+
Polypodiaceae						
Dryopteris prolifer (Retz.) c. chr.	G				+	+
Flowering Plants (after Phillips, 1951)						
Typhaceae						
Typha capensis Rohrb.	R			+	+	+
Potamogetonaceae						
Potamogeton sp. cf. P. crispus L.	A			+	+	+
Najadaceae						
Najas sp.	A			+	+	+
Gramineae						
Aristida junciformis Trin ex Rupr.	R		+			
A. sciurus Stapf.	G			+	+	
Arundinella nepalensis Trin.	R		+	+	+	
Beckeropsis uniseta Stapf ex Robyns	G			+	+	
Bothriochloa glabra (Roxb.) A.Camus	G			+	+	
B. insculpta (Hochst.) A.Camus	G					+
Cynodon dactylon (L.) Pers.	R-G			+	+	
Dichanthium aristatum (Poir.) C.E.Hubb.	G				+	
Danthonia macowanii Stapf.	G	+				
Echinochloa crus-pavonis (H.B.K.) Schult.	G				+	
Ehrharta erecta Lam.	G					+
Eleusine indica (L.) Gaertn.	G					+
Eragrostis plana Nees.	G		+	+	+	+
E. sp.	G	+				
Hemarthria attissima Stapf et C.E.Hubb	R		+	+		
Hyparrhenia glauca Stent.	G		+	+		
H. hirta (L.) Stapf.	G		+	+	+	
Imperata cylindrica (L.) Beauv.	R			+	+	+
Ischaemum arcuatum (Nees) Stapf.	R		+			
Leersia hexandra Sw.	R		+	+	+	
Miscanthidium capense (Nees) Stapf.	R		+			
M. junceum (Stapf.) Stapf.	R			+	+	
Paspalum dilatatum Poir.	G		+	+	+	+
P. distichum Linn.	G			+	+	
P. vaginatum Sw.	R				+	
Pennisetum natalense Stapf.	R		+	+	+	
Phalaris sp.	G			+		
Phragmites communis Trin.	R			+	+	+
Setaria pallidi fusca (Schumach) Stapf. et Hubb.	G			+		
Sporobolus fimbriatus Nees.	G		+	+	+	+
Stenotaphrum secundatum (Walt.) O. Kuntze	R			+	+	+
Cyperaceae						
Carex zuluense C.B.Cl.	G	+	+			
Cyperus articulatus Linn.	R				+	+
C. compressus Linn.	R				+	+
C. difformis Linn.	R					+
C. esculentus Linn.	R					+
C. fastigiatus Rottb.	R				+	
C. leptocladus Kunth.	R					+
C. marginatus Thunb.	R		+	+	+	+
C. rotundus Linn.	R					+
C. sexangularis Nees.	R					+
Fimbristylis ferruginea (L.) Vahl.	R				+	+
F. dichotoma (L.) Vahl.	R				+	+
Mariscus congestus C.B.Cl.	R				+	
Pycreus polystachyos Beauv						+

SPECIES	Type	AREAS Upper River Region Montane	L.T. Zone	Upper River Zone	(Valley Zone) Middle River and Top of Lower River Zone	(Coastal) Lower River Zone
P. mundtii Nees.	R				+	+
Scirpus prolifer Rottb.	R					+
Scirpus setaceus L.	R	+				
S. spp.	R	+	+	+	+	+
Pontederiaceae						
Eichornia crassipes Solms.	F			+	+	
Juncaceae						
Juncus sp.	R					+
Liliaceae						
Ornithogalum zeyheri Baker	R				+	
Amaryllidaceae						
Anoiganthus breviflorus Baker	R				+	
Salicaceae						
Salix babylonica L.	R			+		
S. woodii Seem.	R		+	+	+	
Ulmaceae						
Celtis kraussiana Bernh.	R				+	
Moraceae						
Ficus capreaefolia Del.	R				+	+
F. sycamorus L.	R				+	+
F. spp.	G				+	+
Polygonaceae						
Polygonum setulosum Rich.	R		+	+	+	+
Rumex sp.	R					+
Podostemaceae						
Sphaerothylax sp.	A			+	+	
Rosaceae						
Cliffortia linearifolia Cham. & Schlecht.	R	+	+			
C. sp.	R	+	+			
Leucosidea sericea E. & Z.	G	+	+			
Leguminosae						
Acacia karroo Hayne	G			+	+	+
A. robusta Benth.	G				+	+
Calpurnia intrusa E. Mey.	R		+			
Desmodium sp.	G					+
Meliaceae						
Turraea floribunda Hochst.	G					+
Trichilia roka (Forsk.) Chiov.	R-G				+	+
Euphorbiaceae						
Antidesma venosa Tul.	G					+
Bridelia micrantha Baill.	G					+
Macaranga capensis Sim.	G					+
Anacardiaceae						
Rhus legati Schonl.	R				+	
Rhus sp.	R			+	+	
Aquifoliaceae						
Ilex mitis (L.) Radkl.	R		+			
Celastraceae						
Gymnosporia sp.	G				+	
Icacinaceae						
Apodytes dimidiata E. Mey.	G					+
Flacourtiaceae						
Scolopia mundtii E. & Z.	G		+			
Oliniaceae						
Olinia emarginata Burtt Davy	G		+			

SPECIES	Type	Upper River Region		AREAS Upper River Zone	(Valley Zone) Middle River and Top of Lower River Zone	(Coastal) Lower River Zone
		Montane	L.T. Zone			
Combretaceae						
Combretum erythrophyllum (Burch.) Sond.	R			+	+	
Myrtaceae						
Eugenia natalitia Sond.	G					+
Syzygium guineense (Willd.) D.C.	R				+	
Onagraceae						
Epilobium sp.	G		+			
Jussiaea sp. cf. J. repens Linn.	R					+
Umbelliferae						
Berula thunbergii	R		+			
Ericaceae						
Erica caffrorum Bolus	G	+				
E. leucopelta Tausch.	G	+				
Myrsinaceae						
Rapanea melanophleos (L.) Mez.	G		+			
Primulaceae						
Samolus sp.	G					+
Sapotaceae						
Mimusops dispar N.E.Br.	R				+	
M. obovata forma Sond.	R				+	
Ebenaceae						
Euclea lanceolata E. Mey ex D.C.	G		+			
E. natalensis A.D.C.	G					+
Loganiaceae						
Buddleja salvifolia Lam.	G	+	+			
Scrophulariaceae						
Bowkeria triphylla Harv.	R	+	+			
Plantaginaceae						
Plantago sp.	G					+
Compositae						
Artemesia afra Jacq.	R	+	+			

G = Species characteristic of the banks but not specifically riverine.
R = Typically riverine species.
R-G = Species not specifically riverine which however dominate to the waters edge.
A = Aquatic species.
F = Floating species.

TABLE A13

Concentrations of substances in the Tugela in 1952

Extracted from Caplan, Jackson, Webb, and Middleton, (1952)

	Total Dissolved Solids in ppm.			4hr. Permanganate Oxygen Demand in ppm. of Oxygen			Ammonia in ppm. N.			Nitrites in ppm. N.			Nitrates in ppm. N.		
	L.S.	A.	E.W.	L.S.	A.	E.W.	L.S.	A.	E.W.	L.S.	A.	E.W.	L.S.	A.	E.W.
POINT															
Mlambonjwa	36	71	70	1.0	0.8	1.3	0.2	0.19	0.20	.003	.006	.006	.08	.08	.10
Bergville	42	66	69	(14.2) 2.0	1.1	1.7	0.1	0.09	0.53	.004	.035	.007	.20	.37	.09
Colenso	49	132	83	2.7	1.7	1.8	0.2	0.19	0.20	.004	.021	.012	.18	.48	.11
Tugela Ferry	74	187	140	3.7	1.3	1.9	0.2	0.19	0.0	.003	.019	.015	0.22	.35	.12
Tugela Mouth	-	161	168	(16.4) 7.5	2.0	2.0	(0.43)	0.09	0.11	.004	.022	.008	0.32	.29	.11
TRIBUTARIES															
Little Tugela, Winterton	74	75	73	1.9	0.5	1.5	.20	.47	.14	.006	.014	.030	.12	.64	.10
Little Mooi	63	32	48	3.5	0.8	1.5	.10	.19	.16	.004	.009	.007	.14	.64	.09
Mooi	22	42	39	1.6	1.3	1.7	.28	.19	.03	.003	.014	.009	.10	.19	.16
Mooi at Muden	53	61	93	2.6	1.6	1.9	.38	.28	.09	.004	.017	.018	.16	.16	.10
Little Bushmans, Estcourt	61	73	112	(18.0) 2.4	2.1	9.5	.28	.28	.54	.004	.020	.015	.28	.29	.14
Bushmans, Estcourt	62	62	68	(10.2) 1.6	1.5	1.7	.43	.19	.09	.005	.031	.007	.14	.24	.11
Bushmans, Weenen	76	100	138	2.1	1.2	2.7	.38	.09	.11	.010	.013	.012	.20	.21	.19
Blaauwkrantz	142	150	171	3.6	2.1	1.3	.20	.28	.24	.008	.018	.008	.10	.31	.13
Washbank	693	735	958	1.8	1.2	1.6	.28	.19	.15	.020	.010	.104	.40	.80	.44
Sundays	138	318	326	3.2	1.0	1.6	.10	.19	.11	.007	.008	.009	.18	.35	.09
Klip	112	167	180	3.6	1.9	2.0	0.0	0.0	.03	.014	.017	.012	.24	1.12	.67
Blood	74	25	70	3.4	0.3	2.0	.38	.19	0.0	.002	.007	.007	.08	.13	.07
Incandu	56	59	56	1.1	1.9	1.3	.56	.09	.24	.010	.075	.088	.12	.48	.34
Horn	61	70	93	1.8	2.0	1.9	.20	.47	.17	.002	.024	.010	.14	.24	.12
Ingogo	66	122	118	2.3	2.3	2.9	.38	.19	.17	.009	.029	.011	.08	.35	.21
Ingagane	95	59	108	2.3	3.3	2.5	.20	.28	.25	.003	.022	.035	.18	.40	.12
Buffalo at confluence	163	154	221	6.0	0.8	2.1	.52	.19	.15	.007	.039	.021	.14	.36	.36

( ) Figures in brackets are exceptional values resulting from floods.

L.S. = Late summer.

A. = Autumn.

E.W. = Early winter.

TABLE A14

Average numbers of individuals collected between april 1954 and march 1955 at stations on the Tugela River

	STONES IN CURRENT			MARGINAL VEGETATION			BOTTOM SEDIMENTS		
	Numbers per square foot			Numbers per 10 ft. sweep			Numbers per ¼ square foot		
STATION	Average numbers in summer	Average numbers in winter	Average numbers for the whole year	Average numbers in summer	Average numbers in winter	Average numbers for the whole year	Average numbers in summer	Average numbers in winter	Average numbers for the whole year
Upper National Park	86	128	107	-	-	-			
National Park	72	249	160	159	96	128			
Oliviershoek Bridge	13	191	102	74	148	111			
Bergville	28	94	61	108	159	133	21	16	18
Labuschagnes kraal	8	113	61	93	134	114			
Colenso	29	57	43	60	137	99	48	33	40
Nkasini	39	148	94	68	72	70			
Tugela Ferry	41	153	97	35	207	121			
Ngobevu	27	103	65	71	140	106			
Middle Drift	31	55	43	29	129	79			
Mandini	(1)*	(7)	(4)	67	105	86	44	84	64

* (numbers on rock faces, not stones on rapids)

TABLE A15

Seasons of abundance of some common species in different regions of the river

Species	Upper river	Middle river	Lower river
1. Baetis harrisoni	SW	SW	W
2. B. sp. 1.	SASp	AWS	W (few AS)
3. Centroptilum indusii	S	ASp	W
4. Austrocaenis capensis	SW	S	W
5. Neurocaenis discolor	SW	SA	SA
6. Pseudagrion salisburyense	SW	ASp	W
7. Aphelocheirus schoutendeni	SW	W	S
8. Laccocoris limnigenus	S	SW	S
9. Rhagovelia nigricans	SASp	SASp	AWSp

S = Present in summer.
A = Present in autumn.
W = Present in winter.
Sp = Present in spring.

TABLE A16
The range of chemical conditions in other rivers

RIVER AND AUTHOR	pH	Conductivity in mmho.	Total dissolved solids in ppm.	4 hr. Permanganate oxygen demand in ppm. of oxygen	5 day B.O.D. in ppm. of oxygen	Free and saline ammonia in ppm.	Albuminoid ammonia in ppm.	Nitrites in ppm.	Nitrates in ppm.	Phosphates in ppm.	Sulphates in ppm.	Chlorides in ppm.	Alkalinity as ppm. $CaCO_3$	Calcium as calcium carbonate	Magnesium as ppm. calcium carbonate
The Berg river: Harrison and Elsworth (1958)															
Zone II	4.3 - 5.9	8 - 22	10 - 40	0.6 - 3.6	0 - 2.05	0 - 0.04	0.01 - 0.064	0 - 0.01	0 - 0.19	0 - 0.105	0 - 0.6	3.0 - 9.0	1.0 - 2.0	0.1 - 0.6	0 - 0.7
Zone IIIa	4.7 - 7.6	10 - 72	19 - 124	0.6 - 2.35	0 - 3.5	0 - 0.036	0.006 - 0.124	0 - 0.05	0 - 0.78	0 - 0.092	0 - 6.5	3.6 - 28.6	1.6 - 16.4	1.5 - 3	1.5 - 3
Zone IIIb	5.9 - 7.3	19 - 225	18 - 220	0.3 - 4.81	0 - 5.7	0 - 0.236	0.024 - 0.318	0 - 0.017	0 - 0.63	0 - 0.062	0 - 15.1	7.2 - 92	2.2 - 46	0.6 - 8.0	0.5 - 5.2
Zone IV	6.4 - 8.2	30 - 721	45 - 584	0.6 - 35.7	0.15 - 250	0 - 0.196	0.04 - 0.597	0 - 0.026	0.01 - 0.65	0 - 0.490	0 - 37.0	13.4 - 264	4.4 - 64	1.4 - 15.0	0.8 - 17.8
Zone V	6.4 - 7.5	42 - 390	68 - 381	0.96 - 33.5	0.55 - 3.3	0.004 - 0.298	0.058 - 1.01	0 - 0.014	0.01 - 0.58	0 - 1.125	0 - 23	16.4 - 169.0	5.6 - 57	1.7 - 14.0	1.6 - 18.2
The Vaal river: Stander et alia. (1952)			7 - 110												
The Nile river: Hurst (1952)			167								10	12	127	23 (as Ca)	9 (as Mg)
The Nile river: Abdin (1946)	7.7 - 8.4			4.3 - 7.4					0.04 - 0.25	0.02 - 0.1				98 - 116	
The Ohio river: Streeter and Frost (1924)					(total B.O.D.)										
August 1914			116 - 641	2.8 - 5.1	0.78 - 4.9	0.009 - 0.84	0.14 - 0.51	0.001 - 0.063	0.07 - 0.8		41 - 145	5 - 141	-16 to 184	47 - 165	
January 1914			180 - 350	2.5 - 4.8	-	0.02 - 0.105	0.12 - 0.202	0.002 - 0.005	0.33 - 1.45		-	4.1 - 15	- 3 to 179	-	
The Clydach, Amman, Pedol and Garw: Eriksen Jones (1948)											trace -14	8.8 - 14.8		(as Ca) 1.8 - 3.2	(as Mg) 0.5 - 2
Clydach:	4.4 - 6.8										trace	10 - 12		4.8 - 25.8	1.5 - 5
Amman, Pedol, Garw.	6.8 - 7.8														
The Tees: Butcher et alia. (1937)															
Highforce	6.9 - 7.7		62 - 177	4 - 5	1 - 2	0.15		0.001 - 0.003	0.08 - 0.7		2 - 12	5 - 10		5 - 33	0 - 8
Eryholme	7.4 - 7.9		161 - 357	5 - 6	2 - 8	0.35 - 2.8		0.02 - 0.09	0.01 - 2.1		5 - 71	9 - 27		21 - 84	4 - 32

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Photo 1. Sponge at source of the Bushmans river, Giants Castle.

Photo 2. End of the Source zone at the edge of the Drakensberg escarpment.

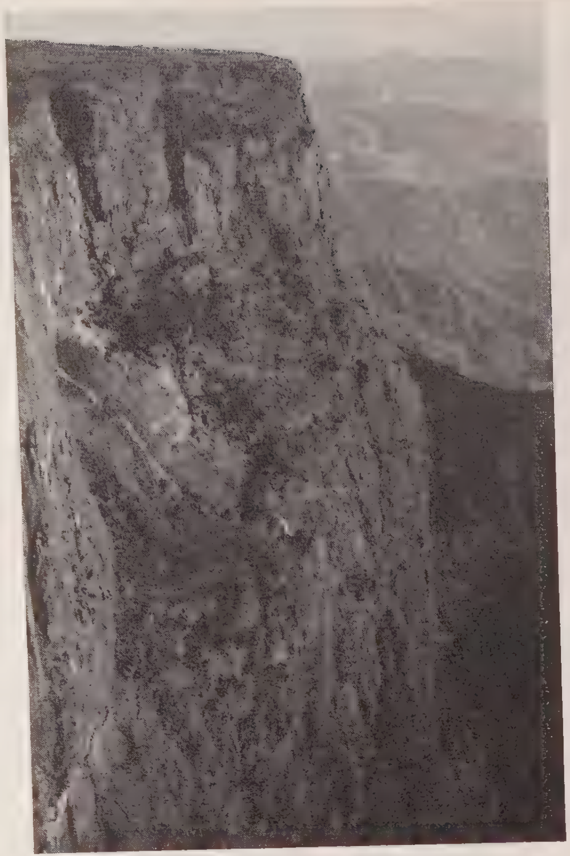


Photo 3. The Waterfall zone.

Photo 4. The Mountain Torrent zone in the Gorge, seen from above.

Photo 5. The Foothill Torrent zone at National Park.

Photo 6. The Foothill Sand Bed zone at Bergville

Photo 7. End of the Foothill Sand Bed zone at Colenso.

Photo 8. Rapids in the Rejuvenated river zone at Hart's Hill.

Photo 9. Rapids in the Rejuvenated river zone at Tugela Ferry.

Photo 10. Rapids at Middle Drift in the Valley Sand Bed zone, during flood.

Photo 11. The lower river at Mandini.

Photo 12. An aerial view of the Tugela river mouth.

14. RECORD OF SPECIES COLLECTED IN THE TUGELA BASIN

Species collected during the survey are listed below. Only those groups which have been satisfactorily identified to species are listed. Other groups are being studied, and will be listed in a later publication.

Where sufficient collections were made to warrant it, the zonation of the species has been indicated.

Collections of flying insects have been made for most groups at various stations on the river. The results cannot be intergrated with the quantitative work of the survey, but serve to indicate the species present. In the cases of the Odonata and Chironomidae these collections give us the best record of the distribution of the species as their pre-imagal stages are not well enough known to be identified.

Key to the Zones used in describing the distribution of species of animals in the Tugela river.

Source	*Zones*
1. Source	Upper River.
2. Waterfall	
3. Mountain Torrent	
4. Foothill Torrent	
5. Foothill Sand Bed	Sand Bed.
6. Rejuvenated River	
7. Valley Sand Bed	
8. Estuarine	
Mouth.	

			Zones
A.	*Turbellaria:*	Dugesia? sp. 1.	5p
	Planariidae	Planariidae sp. 2.	1—5
	Dendrocoelidae	Sorocelis sp. 1.	5p
	Microstomidae	Microstomium sp. 1.	5p
B.	*Nemertea:*		
		Prostoma? sp. 1.	5p
C.	*Nematoda:*		
	Dorylaimidae	Nygolaimus sp. 1.	5p
	Diplogasteridae	Diplogaster sp. 1.	5p
		D. sp. 2.	5p
D.	*Oligochaeta:*		
	Aeolosomatidae	Aelosoma beddardi?	5p
	Naididae	Chaetogaster sp. 1.	5p—8p
		Nais sp. 1.	5p—8p
		N. sp. 2.	5p
		N. sp. 3.	5p
		Stylaria sp. 1.	5p
		Slavina sp. 1.	5p
		Dero limosa?	5p
		Aulophorus furcatus?	5p
		Naidium sp. 1.	5p
		Pristina sp. 1.	5
	Tubificidae	Tubifex sp. 1.	5p
		T. sp. 2.	5p
		Limnodrilus sp. 1.	5—8
		Branchiura sowerbyi Bedd.	5—8
	Lumbriculidae	Lumbriculidae sp. 1.	5—8
		L.? sp. 2.	5—8
E.	*Hirudinae:*		
	Glossiphoniidae	Glossiphonia? sp. 1.	5p
		Helobdella? sp. 2.	5p
F.	*Cladocera:*		
	Daphniidae	Daphnia pulex (de Geer)	5
		Simocephalus capensis (Sars)	5—8
		S. vetuloides (Sars)	5—8
		Ceriodaphnia quadrangula (O.F.M.)	5

			Zones
		C. cf. pulchella Sars	5
		Moina propinqua? Sars	5—8
	Bosminidae	Bosmina longirostris (O.F.M.)	5—8
	Macrothricidae	Macrothrix propinqua Sars	5—8
		Ilyocryptus sordidus (Lièven)	5—8
	Chydoridae	Leydigia cf. microps Sars	5
		L. cf. quadrangularis (Leydig)	5
		L. cf. macrodonta Sars.	5
		Alona cf. affinis (Leydig)	5—8
		A. Cambouei	5—8
		A. cf. gutatta Sars.	5—8
		A. cf. quandrangularis (O.F.M.)	5—8
		A. cf. striolata Sars.	5—8
		Chydorus gibsoni Brady	5—8
		C. cf. sphaericus (O.F.M.)	5
		Pleuroxus aduncus (Jurine)	5—8
G.	*Copepoda:*		
	Diaptomidae	Paradiaptomus lamellatus Sars.	1
		Tropodiaptomus spectabilis Kieffer	5—8
	Cyclopidae	Macrocyclops albidus (Jurine)	5
		Tropocyclops confinis Kieffer	5—8
		Ectocyclops hirsutus Kieffer	
		Eucyclops euacanthus (Sars)	5
		E. cf. gibsoni (Brady)	5
		E. cf. sublaevis (Sars)	5
		E. cf. speratus (Lilljeborg)	5
		Paracyclops fimbriatus (Fisher)	5—8
		P. poppei (Rehberg)	5p
		P. cf. affinis (Sars)	5
		Cyclops (Microcyclops) cf. varicans Sars	5
		Mesocyclops leuckarti (Claus)	5
		M. cf. hyalinus (Rehberg)	5
		Thermocyclops schuurmanae Kieffer	
	Canthocamptidae	Elaphoidella bidens decorata (Sars)	5p
		Harpacticus sp.	5
H.	*Ostracoda:* (Identifications doubtful)		
	Cyprididae	Eucypris sp. 1.	
		Isocypris sp. 1.	
		I. priomena Muller	
		Cypria capensis Sars	

		Zones
	Cypretta arcuata	
	C. minna (King)	
	Zonocypris cordata?	
	Z. tuberae?	
	Ilcyocypris australiensis	
	Herpetocypris chevreuxi	
	Typhalocypris sp. 1.	
	Cypridopsis gregaria (Sars)	
	C. glabrata Sars.	
	C. hirsuta Sars.	
	C. reniformis Sars.	
I. *Malacostraca:*		
Mysidacea	Gastrosaccus brevifissura Tattersall	9
Tanaidae	Tanais annectens Brnrd.	9
	T. philetaerus Stebb.	9
Isopoda:		
Jaeridae	Protojanira perbrincki Brnrd.	3
Eurydicidae	Pontogeloides latipes Brnrd.	9
Amphipoda:		
Gammaridae	Crangonyx robertsii (Meth)	1
Talitridae	Talorchestia sp.	9
	Orchestia sp.	9
Corophilidae	Corophium prob. triaenonyx Stebb.	9
Aoridae	Grandidierella sp., c.f. bonnieri Stebb.	9
Decapoda:		
Grapsidae	Sesarma catenata Ort	9
	S. eulimene de Man	9
Potamonidae	Potamon sidneyi Rathburn	3—8
	P. dubius (Br. Cap.)	3
	P. warreni Calman	3—8
	P. perlatus (M. Edw.)	3
Upogebiidae	Upogebia africana Ortmann	9
Penaeidae	Penaeus monodon Fabr.	9
	P. japonicus Bate	9
	Metapenaeus monoceros Fabr.	9
Atyidae	Caridina typus M. Edw.	9
	C. nilotica var. natalensis P. Roux	8

		Zones
Palaemonidae:	Macrobrachium cf. idella Hilg.	8
	M. equidens Barnard	8
	M. lepidactylus Hilg.	7—8
	Palaemon pacificus Stimpson	9
J. *Plecoptera:*		
Nemouridae	Aphanicercella? sp.	1—3
Perlidae	Neoperla spio (Neuman)	4—8
K. *Ephemeroptera:*		
Prosopistomatidae	Prosopistoma crassi	5—6
	Prosopistoma sp.	7
Polymitarcidae	Ephoron savigni (Pict.)	5
Ephemeridae	Eatonica schoutedeni Navas	5
Oligoneuriidae	Oligoneuriopsis lawrencei Crass	3
	Elassoneuria trimeniana McLach.	5—7
Baetidae	Austrocloeon africanum Brnd.	5
	A. virgiliae Brnd.	4—7
	Pseudocloeon inzingae Crass	3—5
	P. maculosum Crass	4—5
	P. vinosum Brnd.	4—7
	Baetis harrisoni Brnd.	3—7
	B. bellus Brnd.	4—7
	B. cataractae Crass	3
	B. sp. 1	5—7
	B. glaucus Crass	5—7
	B. lawrencei Crass	1
	B. sp. 2	4—7
	B. parvulus? Crass	3, 4
	Acentrella natalensis Crass	1—4
	A. monticola Crass	3
	Centroptilum sudafricanum Lest.	1—4
	C. excisum Brnd.	4—7
	C. indusii Crass	5—7
	C. medium Crass	5—7
	C. parvum Crass	3, 4
	C. varium Crass	4—6

		Zones
	C. venustrum Brnd.	5—7
	C. sp. 1	6, 7
	C. sp. 2	3—6
	C. sp. 3	4
	C. sp. 4	6
	Centroptiloides bifasciatum Lest.	6, 7
Brachycercidae	Austrocaenis capensis Brnd.	1—7
	Caenis sp. 1	4—7
	C. sp. 2	1—7
	C. sp. 3	4—7
	Neurocaenis discolor (Brnd.)	3—7
	N. reticulatus (Brnd.)	5
Leptophlebiidae	Aprionyx tricuspidatus Crass	3
	Adenophlebia auriculata Eaton	1—4
	A. sylvatica Crass	3
	Castanophlebia calida Brnd.	3
	Euthraulus elegans Brnd.	3—7
Ecdyonuridae	Afronurus peringueyi (E.P.)	4
	A. harrisoni Brnd.	3
	A. sp. 1	5—7
	Notoneurus cooperi Crass	5—7

Images

L. *Odonata: Zygoptera*		
Synlestidae	Chlorolestes fasciata Burm.	4—5
	C. tessellata Burm.	7
	C. longicauda Burm.	5—6
Lestidae	Lestes plagiatus Burm.	5—6
Protoneuridae	Elattoneura glauca Sélys	5—6
Platycnemididae	Allocnemis leucosticta Sélys	5—6
Coenagriidae	Ceriagrion glabrum Burm.	4—7
	Pseudagrion acaciae Forst	7
	P. citricola Brnd.	5—6
	P. glaucescens Sélys	7

		Zones
	P. kersteni Gerst.	7
	P. makabusiensis Pinhey	7
	P. natalense Ris.	4—7
	P. pseudomassaicum Pinhey	7
	P. salisburyense Ris.	4—7
	P. sjöstedti Först	7
	Ischnura senegalensis Ramb.	7
	Enallagma glaucum Burm.	4—7
	Agriocnemis exilis Sélys	7
Agriidae	Phaon iridipennis Burm.	7
Chlorocyphidae	Chlorocypha caligata Sélys	4—7
	C. fitzsimonsi Pinhey	5
Anisoptera		
Gomphidae	Notogomphus praetorius Sélys	4—7
	Paragomphus cognatus Ramb.	3—5
	P. hageni Sélys	6
	Ceratogomphus pictus Hagen	6
Aechnidae	Aechna minuscula McLach.	6
	Anaciaeschna triangulifera McLach.	7
	Anax speratus Hagen	6
Libellulidae	Tetrathemis polleni Sélys	7
	Orthetrum brachiale (Pal. de Beauv.)	6
	O. caffrum (Burm.)	4—7
	O. crysostigma subsp. chrysostigma (Burm.)	7
	O. farinosum Förster	6, 7
	O. stemmale subsp. capen Cesalvert.	4—7
	O. stemmale subsp. kalai Longfield	7
	Palpopleura jucunda Ramb.	7
	P. lucia. (Drury)	6
	Hemistigma albipuncta Ramb.	6
	Diplacodes lefebvrei Ramb.	7
	Crocothemis erythraea (Brullé)	6
	C. sanguinolenta (Burm.)	3—5
	Brachythemis leucosticta (Burm.)	7
	Philonomon luminans (Karsch.)	7
	Sympetrum fonscolombei (Sélys)	4—7
	Trithemis annulata (Beauv.)	6, 7

		Zones
	T. arteriosa (Burm.)	6, 7
	T. dorsalis (Ramb.)	5
	T. kerbyi subsp. ardens Gerst.	6, 7
	T. risi Longf.	4—7
	T. stictica (Burm.)	6, 7
	Zygonyx natalensis (Martin)	7
	Z. torrida (Kirby)	6, 7
	Rhyothemis semihyalina (Desj.)	7
	Pantala flavescens (F.)	7
M. *Hemiptera:*		
Hydrometridae	Hydrometra stagnorum	4—7
Mesoveliidae	Mesovelia vittigera Horvath.	5—7
Gerridae	Gerris hypoleuca Gerstacher.	5—7
	G. swakopensis Stål	7
	G. sp. 1	7
Veliidae	Microvelia major Poisson	4—7
	Rhagovelia nigricans Burm.	4—7
Notonectidae	Enithares prob. chinai Jaczewski	4—7
	E. sobria Stål	7
	E. sp. 1	4
	E. v-flavum Reut.	4—7
	Anisops sp. cf. aglaia Hutch.	7
	A. debilis Gerst.	7
	A. gracilis Hutch.	5—7
	A. gracilloides Brooks	5—7
	Nychia limpida limpida Stål	4—7
	Nychia sp.	5—7
Pleidae	Plea pullula Stål	4—7
	P. piccanina Hutchinson	4—7
Corixidae	Micronecta hessei Hutch.	4—7
	M. piccanin Hutch.	4—6
	M. scutellaris Stål	5—7
	Sigara sjostedti Kirk	5—7
Naucoridae	Aphelocheirus schoutedeni Montandon	5—7

			Zones
		Laccocoris limnigenus Stål	4—7
		Macrocoris flavicollis Signoret	4—7
	Nepidae	Nepa sp. cf. cinerea	5—7
		Ranatra sp. cf. linearis	5—7
	Belostomatidae	Sphaerodema nepoides Fabricius	4—7
	Helotrephidae	Naboandelus sp.	7
		Ochterus marginitus	7
N.	*Trichoptera:*		
	i. *Larvae:*		
	Sericostomatidae	Dyschimus sp. near thrymmifer	3
		Georodes sp.	3—4
	Leptoceridae	Adicella sp.	5
		Oecetis modesta (Barnard)	5
		Arthripsodes sp. A.	3—4
		A. sp. B.	
		Leptocerus sp.	6
		Leptocerus harrisoni Barnard	4—5
		Leptoceridae sp.	5
		Leptocerina spp.	5—7
		Mystacidini spp.	1—4
		Oecetini sp.	5
		Triaenodes sp.	5—7
	Hydropsycheidae	Hydropsyche ulmeri (Barnard)	3—6
		H. sp. A.	3—6
		H. sp. B.	6
		H. sp. C.	4
		Cheumatopsyche? afra (Mosely)	6
		Ch. maculata Mosely	3—4
		Ch. near maculata type A.	6—7
		Ch. near maculata type B.	3—4
		Ch. zuluensis (Barnard)	4—7
		Ch. near zuluensis type A.	6
		Ch. near zuluensis type B.	6
		Ch. triangularis Ulmer	7
		Chloropsyche 1. (Barnard)	5
		Polymorphanisus bupunctatus (Brauer)	5—6
		?Protomacronema sp.	5

		Zones
Polycentropidae	Polyplectropus sp.	4
	Pseudoneureclipsis sp. A.	4—5
	P. sp. B.	4
Psycheomyidae	?Ecnomus sp. A.	4—5
	?Ecnomus sp. B.	3—4
	?Ecnomus sp. C.	3
	?Lype sp.	3
Philopotamidae	Chimarra sp. A.	4
	Chimarra sp. B.	4
Hydroptilidae	?sp. A.	2—4
	?sp. B.	3—7, 7
	Hydroptila capensis Barnard	1—4, 6
	Argyrobothrus sp.	(4) (6)
	?sp. C.	5
ii. *Imagines:*		
Sericostomatidae	Dyschimus ensifer Barnard	4
Leptoceridae	Adicella sp.	4
	Athripsodes fissus (Ulmer)	4
	?A. sp. nov.	4
	Oecetis modesta (Barnard)	6
	Setodes squamosa Mosely	4
Hydropsycheidae	Hydropsyche ulmeri Barnard	5—7
	H. sp. near longifurca Kimmers	6, 7
	H. ? sp. ulmeri Barnard	5
	Cheumatopsyche afra (Mosely)	4
	C. falcifera (Ulmer)	7
	C. maculata (Mosely)	4
	C. thomasseti (Ulmer)	4
	C. triangularis (Ulmer)	4—6
	C. urema Mosely	4
	C. zuluensis (Barnard)	4—7
	Ch. ? zuluensis (Barnard)	6
Polycentropidae	Dipseudopsis? capensis Barnard	5
	Polyplectropus? sp. n.	4
Psycheomyidae	Ecnomus thomasseti Mosely	4
	Ecnomus? natalensis Ulmer	4

		Zones
	Paduniella ankya Mosely	4
	P. capensis Barnard	4
Philopotamidae	Chimarra sp.	4
	C. sp. near ambulans	4
Hydroptilidae	Hydroptila capensis Barnard	1—4 (6)

O. *Lepidoptera*: Pyralididae.

P. *Coleoptera:*

1. Haliplidae:

2. Dytiscidae:

Amarodytes peringueyi Rég.	5
Bidessus sharpi Rég.	7
Canthydrus nigerrimus O-C	7
Canthydrus notula E-.	5
Canthydrus quadrivittatus Bol.	5
Canthydrus sedilloyi Rég. var. gutticollis Rég.	5
Clypeodytes coarcticallis Rég.	6
Clypeodytes meridionalis Rég.	4—7
Copelatus polystrigus Shp.	7
Guignotus harrisoni O-C.	4—7
Hydaticus servillianus Aubé	5
Hydrovatus validicornis Rég.	5
Hyphydrus aethiopicus B.B.	7
Hyphydrus? caffer Boh.	
Laccophilus adspersus Boh.	5
Laccophilus amplicatus Rég.	5—6
Laccophilus congener O-C	7
Laccophilus continentalis Gehn.	7
Laccophilus cyclopis Shp.	4
Laccophilus lineatus Aubé	4—7
Laccophilus olsoneffii Guign.	(5)
Laccophilus pilitaris Rég.	5—7
Laccophilus sp.	7
Philaccolus lineatoguttatus Rég.	4
Neptosternus ornatus Shp.	6, 7
Potamonectes vagrans O-C.	4—5—6
Yola natalensis Rég.	5
Yola subopaca Rég.	4
Yola tuberculata Rég.	7

	Zones
3. Gyrinidae:	
Aulonogyrus abdominalis Aubé	5—7
Aulonogyrus amoenulus Boh.	7
Aulonogyrus alternatus Rég.	5
Aulonogyrus sesotho Brink.	3—5
Dineutus aerus Klug.	7
Gyrinus natalensis Rég.	5—6
Orectogyrus conformis Rég.	4—5
Orectogyrus oscari Apetz.	5
Orectogyrus polli Rég.	5—7
4. Coccinellidae:	
Scymus sp? fallax Mader	
Nephus sp? augustus Casey	
5. Hydrophilidae.	
6. Hydroscaphidae.	
7. Hydraenidae.	
8. Psephenidae.	
9. Dryopidae.	
10. Elmidae.	
11. Helodidae.	
12. Chrysomelidae:	
Melosoma discolor Stål	5
13. Halticidae:	
Haltica cuprea Jac.	5
Aphthona marshalli Jac.	6
14. Galerucidae:	
Estcourtiana litura Gerst var.	4—6
15. Curculionidae:	
Baris sp.	7
Coeliodes celastri Rosen.	5
Piezotrachelus magnirostris Wagn.	5

Q. *Diptera:*

1. *Imagines*

a. Blepharoceridae:	
Elporia flavopicta Edwards	3—6
Elporia hiemis Stuckenberg	1
E. natalensis Stuck.	3—4
E. natalensis sub. sp. oliffi Stuck.	3
E. scruposa Stuck.	3

		Zones
b. Psychodae:		
Psychoda alternata Say		1
Psychoda dentata Tonnoir		4
Telmatoscopus (Arisemus) sp. nov.		3
c. Culicidae:		
Dixinae	Dixa bicolor Wood	3—4
Chaoborinae	Chaoborus (Sayomya) microstictus Edwards	4
Culicinae	Anopholes ardensus Theo.	4
	Anopholes cinereus Theo.	4—6
	Anopholes demeilloni Evans	7
	Anopholes listeri de M.	5
	Culex andersoni subsp. bwambanus Edwards	5—6
	Culex salisburiensis Theo.	1—6
	Culex tigripes Grp. & Char.	5
	Culex univittatus Theo.	5
	Culex vansomereni draconis Ing. & de M.	5
	Theobaldia longiareolata Macquart.	4
d. Simuliidae:		
Simulium bovis de M.		6, 7
S. damnosum Theo.		5, 6, 7
S. debegene de M.		4, 5
S. dentulosum Roub.		5
S. medusaeforme Pom.		1—6
S. nigritarsis Coq.		1
S. unicornutum Pom.		1
e. Chironomidae:		
Tanypodinae:		
Pentaneura appendiculatus Kieffer		5—6
Pentaneura cornata Freeman		5—6
P. cygnus Kieffer.		5
P. dusoleili Goethebuer.		4—6
P. nigromarmorata Goethebuer.		4—5
P. palpalis Goethebuer.		4
P. sp. nov.		5—6
P. tinctoria Freeman		5—6
P. trifascia Freeman		4

	Zones
Tanypus lacustris Kieffer	5
Procladius brevipetiolatus Goethebuer	4—7
Corynoneurinae:	
Corynoneura scotti Freeman	4
Thienemanniella analis Freeman	4
T. antennata Freeman	4—7
T. lineola Freeman	4
Orthocladinae:	
Metriocnemus dewulfi Goethebuer.	5—7
M. scotti Freeman	4
Cardiocladius latistilus Freeman	4
C. oliffi Freeman	4
Cricotopus albitibia Walker	5—6
Cricotopus bicinctus var plumbeus Goethebuer.	5—6
C. bizonatus Freeman	7
C. bergensis Freeman	5—6
C. harrisoni Freeman	5—6
C. obscurus Freeman	4
C. scottae Freeman	5
C. sp. nov.	5
Orthocladius bergensis Freeman	4—7
O. lobiger Freeman	4
Procladius brevipetiolatus Goethebuer.	4—7
Pseudothocladius similis Freeman	4
Chaetocladius excerptus Walker. subsp. natalensis Freeman	4
Nanocladius biloba Freeman	4
N. brevitarsis Freeman	5—7
N. claviger Freeman	4
N. ephippium	4
N. niveipluma Freeman	5
N. vitellinus Kieffer.	4—7
Limnophyes spinosa Freeman	4—7
Trichocladius capensis Freeman	4—7
Trichocladius micans Freeman	4—7
Pseudosmittia conigera Freeman	5
Tanytarsini:	
Tanytarsus fuscus Freeman	4—7
T. (Calopsectra) nigricornis Goethebuer.	4—7

	Zones
T. (Cladotanytarsus) pseudomancus Goethebuer.	4
Cladotanytarsus sp.	
Chironomini:	
Microtendipes lentiginosus Freeman	5
M. taitae Kieffer.	4
Stictochironomus festivus Kieffer.	5—7
Dicrotendipes peringueyanus Kieffer.	5
D. pilosimanus Kieffer.	5
Cryptochironomus coronatus Kieffer.	5
Polypedilum alticola Kieffer.	4
P. laterale Goethebuer.	4
P. kibatiense Goethebuer.	4
P. natalensis Kieffer.	5
P. pruina Freeman	5—6
P. quinqueguttatum Kieffer.	5—7
P. scotti Freeman.	4—7
P. tridens Freeman	4—6
Chironomus (Cryptochironomus) albomarginatus Kieffer.	5—6
C. biclavatus Freeman	5
C. caffrarius Kieffer.	5
C. forcipatus Freeman	4—6
C. lindneri Freeman	5—6
C. monilis Freeman	5—6
C. palustris Kieffer.	5—6
C. pulcher Wiedsmann.	5—6
C. reductus Freeman	5
Stempellina truncata Freeman	4
f. Ceratopogonidae:	
Atrichopogon hirsutipennis Ing. & Macfie.	4—5
A. sp.	7
Bezzia pistiae Ing. & Macfie.	5
Brachypogon sp.	3
Ceratopogon sp. nov.	4
Dasyhelea fusca Ing. & Macfie.	4
Dasyhelea sp.	4
Lasiohelea sp.	4
Palpomyia oliffi Freeman	4

Summary

A chemical and biological survey of the Tugela river, Natal is described. Some relationships between physical and chemical conditions in the river and the geology and climate of the basin are indicated. The flora and fauna of the main river is described, and the zonation of species in the river, and seasonal variations in the communities at various stations in the zones are delineated.

Some relationships between the physical and chemical conditions in the basin, and the distribution and seasonal variations of the biological communities are indicated. Comparisons are made with other rivers. It is concluded that the Tugela river as a type in Southern Africa, falls intermediate between temperate and sub-tropical conditions.

Mise au point de systématique dans le genre Difflugia

par

L. Decloître

Dans „KRYTENKY (Testacea) tunky na hradku u kunratic (Praha)", en 1952, M. Stepanek décrit une Difflugia nouvelle, variété de *Difflugia oblonga* qu'il nomme *vas*. Or ce terme est préoccupé.

En 1874, Leidy décrit une *Difflugia vas* dans Proc. Acad. Philadelphia, page 155; puis elle est reconnue par Certes en 1889 et par Cash en 1891.

En 1879, Leidy en fait une variété de *Difflugia pyriformis* dans Rhiz. N. Amer: Penard en fait de même en 1890, Schaudinn en 1879, Lagerheim en 1901 et Thiebaud-Favre en 1906, Landacre Cushman-Henderson en 1905, Odell en 1905, Witelegge en 1886 et Hempel en 1898.

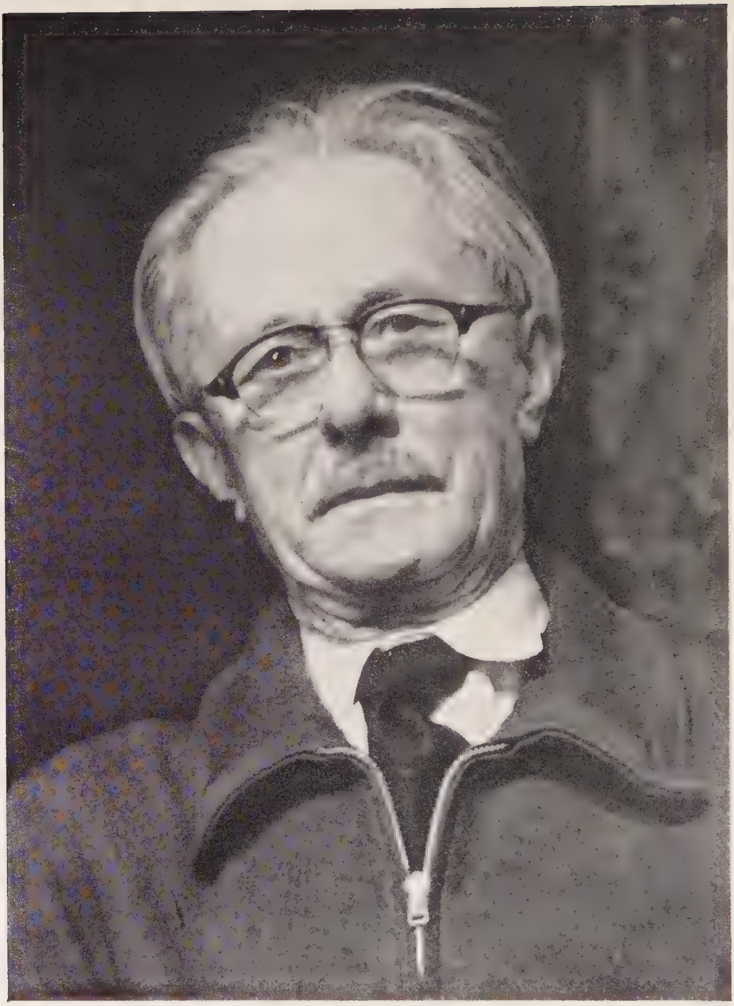
Cette variété est celle que Penard décrit en 1902 sous le nom de *Pontigulasia spectabilis* et que Schouteden reconnait comme étant identique à *Difflugia vas*. Il en fait donc avec raison *Pontigulasia vas* (Leidy) Schouteden.

Elle a été décrite sous le nom de *P. spectabilis* par Penard en 1902, Olivier en 1936, Edmondson en 1912, Brown en 1910, Bartos en 1940, Kourov en 1925, Decloitre en 1947, van Oye en 1948, Fantham-Porter en 1945, Stepanek en 1952, Edmondson-Kingman en 1913, Daday en 1905, Conrad en 1942, Hoogenraad-de Groot en 1952, Margaleff en 1955, Chardez en 1956, Rampi en 1957 et Grospietsch en 1958.

Elle a été decrite sous le nom de *Pontigulasia vas* par Deflandre en 1927, Cash-Hopkinson-Wailes en 1909, par Wailes en 1912, par Penard en 1911, en 1914 et par Stump en 1936.

Or depuis longtemps les auteurs sont d'accord pour faire *D. pyriformis* et *oblonga* comme synonymes. Stepanek est lui-même du cet avis.

Donc il ne peut pas y avoir de *D. oblonga* var. *vas*. C'est pourquoi, selon les règles de la nomenclature, il est indispensable de changer la dénomination de Stepanek. Nous proposons *Difflugia oblonga* var. *stepaneki* (Stepanek) comb. nov. pour *Difflugia oblonga* var. *vas* Stepanek pour respecter les régles admises dans la nomenclature.



P. D. DAMAS (1877—1959)

Personalia

P. D. Damas

On 23 April 1959 died Philippe Désiré Damas, the so well-known author of the biology of the Gadides.

He was born at Seraing-sur-Meuse (Belgium) on May 8, 1877.

Under the influence of Eduard Van Beneden he studied zoology and began his career with the comparative anatomy and embryology of Assidians.

He became a doctor Rerum naturalis in July 1901, and in 1902 he was at the top in the universitary competition, which is a very great distinction in Belgium.

After his studies he travelled to Dröbak, Helgoland and Bergen, where he stayed to work with Johan Hjort.

From 1904 till 1909 he became professor of oceanography at the „Museum" of Bergen - nowadays university of Bergen.

On board of the „Michael Sars" he worked intensely on problems of marine biology and fisheries. He became one of Hjort's most outstanding collaborators and in 1905 he received the Nansen prize of the Academy of Science of Christiana (now Oslo).

At the moment he left Norway (in 1909) he was awarded the prize of the „Belgica" by the National Academy of Belgium.

In 1910 he became professor of zoology at the university of Liége. Though he had far too many charges, he formed many excellent zoologists and directed their research towards marine biology.

The two world wars have damaged his institute twice, so he lost much time on reorganizing his laboratory.

The list of his publications is not very long, but every title represents a work of real importance.

Belgium is the poorer for his death; he was one of the country's most qualified and reputed marine biologists.

P. van Oye

Publications of D. Damas

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W. T. EDMONDSON a.o.: „Wards & Whipple's Fresh-Water Biology" Second Edition. John Wiley & Sons, Inc. New York. 1248 pages. $ 34.50.

Since 1918 knowledge of fresh-water invertebrates of North America has developed to such an extent that not only a revised but even a rewritten edition of Fresh-Water Biology had become necessary. This has now been done under the editorship of W. T. EDMONDSON, professor at the University of Washington, Seattle.

The number of authors who wrote the various chapters has increased from 27 to 51.

The introduction explains the composition of the book, how it is conceived and how it ought to be used.

WARD's orginal introduction of 1918 — rightly considered as obsolete — was left out. Also SHELFORD's chapter on the Conditions of Existence — a very short introduction to limnology — has been omitted.

Moreover the chapter „Methods of Collecting and Photographing" by REIGHARD was replaced by a more concised survey on „Method and Equipment" by W. T. EDMONDSON.

The contents of various chapters has become more extensive, e.g. the one on Bacteria — which is followed by a new chapter on Fungi Phycomycetes.

In most cases the chapters were enlarged and the latest data concerning America added. It is a book intended for students of North America, but most chapters will be of the greatest use for students of other countries. In most cases the book will help in determining the species.

It is an utterly new edition and we must be thankful to prof. EDMONDSON to have undertaken the extensive task of revising the old handbook.

On the insects we find a series of new special chapters: Ephemeroptera, Odonata, Plecoptera, Hemiptera, Neuroptera, Coleoptera, Trichoptera, Lepidoptera, Diptera, which in the 1918 edition were treated in one single chapter under the heading of Aquatic Insects.

Technical and sanitary problems that were treated in the old edition were omitted, as this book in the first place is a guide to the identification of fauna and flora of the inland waters of North America above the Rio Grande.

Every chapter concludes with a reference in which the latest publications are mentioned. P.v.O.

ED. BORNET & CH. FLAHAUT: „Révision des Nostocacées hétérocystées contenues dans les principaux herbiers de France"
H. R. Engelmann (J. Cramer) Weinheim (Bergstr.)
Réimpression 1959, 262 p.

For a long time many classic books had become so rare that libraries, institutes and laboratories could not possibly get them, though numerous students badly wanted parts on the systematical classification.

Therefore it was a good idea of the publisher H. R. Engelmann (J. Cramer) in Weinheim to give reprints of what he called „Later Starting Point Books

for Botanical Nomenclature". The first of the series is the above-mentioned „Révision des Nostocacées hétérocystées contenues dans les principaux herbiers de France" containing a very fine introduction by BOURRELLY on the life and works of the authors BORNET and FLAHAUT.

This introduction impresses by its purely human touch. Furthermore it also gives a complete bibliography of the algological works of the authors.

The body of the publication is the exact reprint of the 4 publications of BORNET and FLAHAUT with the orginal text and pagination just as they were in 1885—1888 in the Annales des sciences Naturelles Botaniques, vol. 3, 4, 5 and 7.

There is no doubt that this new series will be of great use to algologists all over the world.

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Vol. XIV 3—4

CONTENTS

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